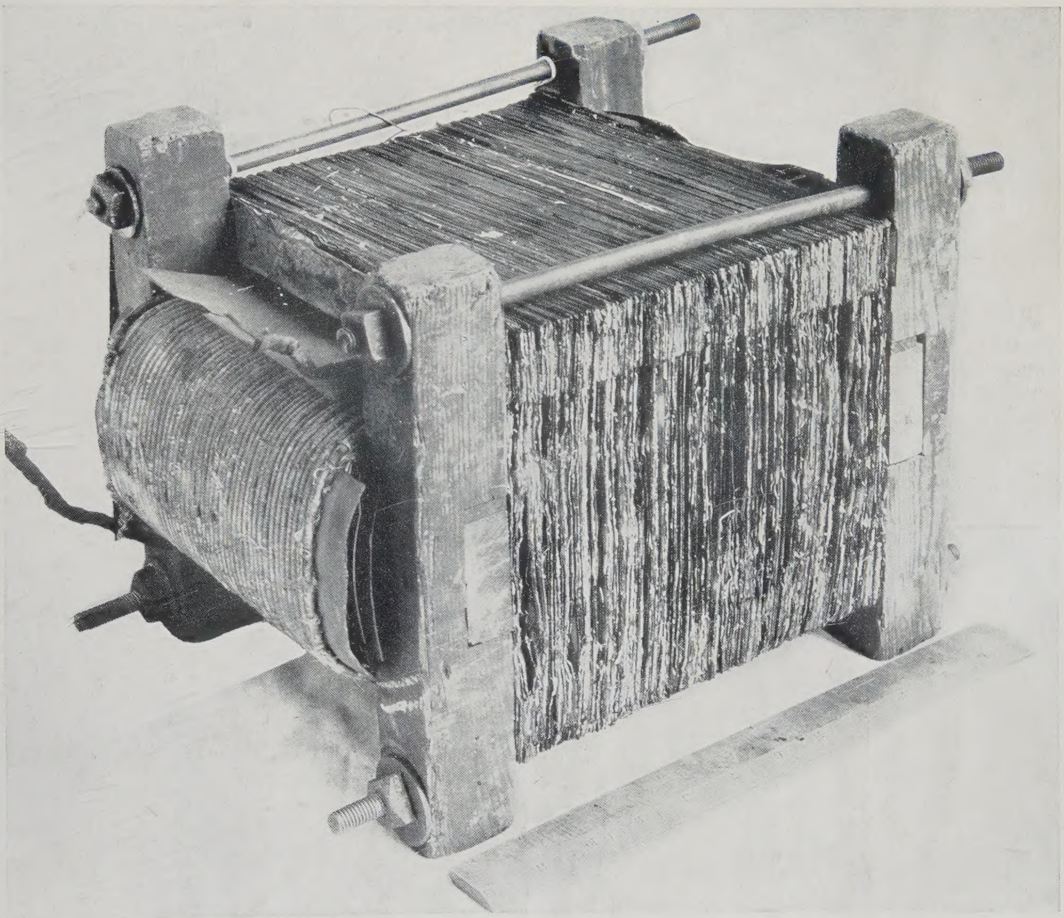
Electrical Engineering

March
1936



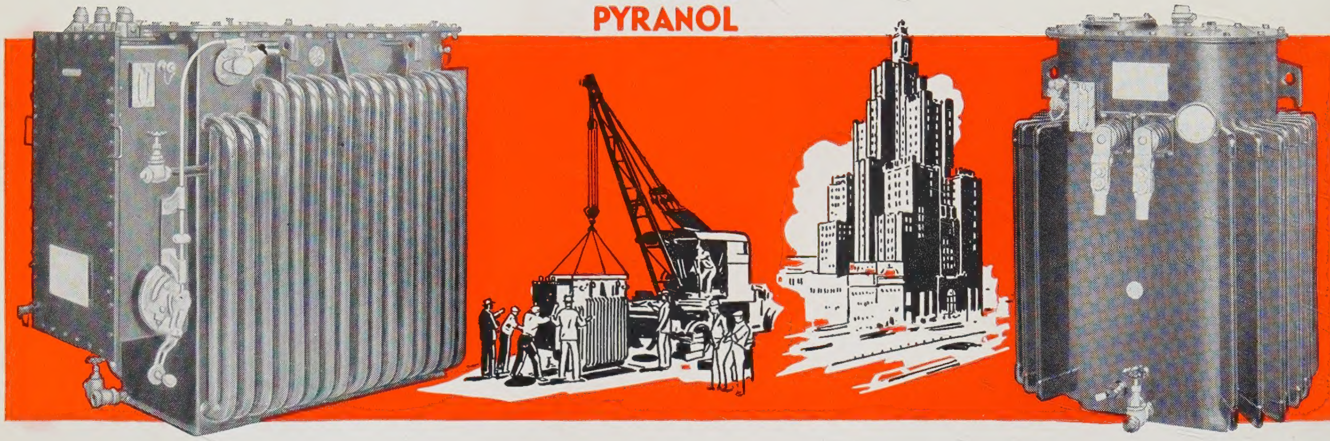
Published Monthly by the
American Institute of Electrical Engineers

HOW G-E PYRANOL TRANSFORMERS Cut Total Installed Transformer Costs

THE 1935 revision of the National Electrical Code permits the installation of noninflammable, nonexplosive G-E Pyranol transformers indoors with many of the restrictions applying to oil-insulated transformer installations eliminated. In each of the applications pictured, G-E Pyranol transformers offer an opportunity for savings in total installed transformer cost. Complete information is contained in Bulletin GEA-2048, "G-E Pyranol Transformers." General Electric, Schenectady, N.Y.

YOU CAN'T BURN

PYRANOL



In Vaults—under sidewalks, streets, or in buildings—such as are common in network systems, G-E Pyranol transformers afford savings because they are smaller. Thus they permit smaller, less expensive vaults, and less expensive methods of connecting the feeders.

In Buildings—apartments, offices, theaters, hotels, hospitals, and schools—savings are realized because expensive fireproof vaults are unnecessary for Pyranol transformers. A simple metal grill meets the requirements of the National Electrical Code.

Transportation—in locomotives, railway cars, docks, and ships, G-E Pyranol transformers are particularly applicable since safety requirements can be met with minimum expense. Pyranol transformers for heating and lighting railway cars have been operating for more than three years with remarkable service records.

In Industry—savings are often possible, because Pyranol transformers can be installed immediately adjacent to the load, eliminating long runs of secondary copper and improving operating characteristics. Vaults are unnecessary; valuable floor space can be saved. Twenty-three per cent in total installed cost was saved in a recent installation.

300-31

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This Month—

Front Cover

One of the earliest transformers designed by William Stanley in 1885 during his experiments at Great Barrington, Mass., where he established the first alternating current system in America on March 20, 1886; the 50th anniversary of this event is being celebrated this month by meetings of many of the Institute's Sections. The primary of this transformer was wound for 500 volts; the secondary for 100 volts. It is the prototype of all transformers now used on the great power systems of today.

Photo courtesy Westinghouse Elec. and Mfg. Co.

Special Articles

A.I.E.E. Papers

—Turn to next page

Discussions

In This Issue—

THE fiftieth anniversary of the establishment of the alternating current system in America will be observed fittingly by special meetings to be held by many of the Institute's Sections. In further commemoration of this event, an article is published in this issue outlining some facts concerning the establishment of this system in Great Barrington, Mass., on March 20, 1886, and other early history of the system, by 2 prominent past-presidents of the Institute (*pages 228–35*). Additional historical data relating to the establishment of the alternating current system may be found in the account of the presentation of the 1935 Edison Medal to Dr. L. B. Stillwell, another past-president (*pages 300–04*).

STANDARDS for sound level meters have been under preparation for some months by a committee of the American Standards Association; recently they were approved as "Tentative American Standards by the A.S.A. Comments and suggestions based upon experience with meters conforming to these standards are solicited (*pages 260–3*).

WITH an all-time record of 442 railroad certificates validated, out-of-town registration for the Institute's 1936 winter convention showed a further increase over last year. A complete report of the convention and its various attractions is presented in the news pages of this issue (*pages 297–9*).

SURGE VOLTAGES across the windings of current transformers are reduced considerably by the use of specially designed protective devices; the effect on transformer accuracy during normal operating conditions is negligible, and the safe operation of relays during system faults is not impaired appreciably (*pages 254–60*).

STANDARDS for calibration of microphones have been under consideration by a committee of the American Standards Association for some time; a report of the work of this committee appears in this issue in order that those interested might have an opportunity to submit constructive criticism and discussion (*pages 241–5*).

POWER FACTOR is one of the several criteria of the deterioration of such complex liquid dielectrics as petroleum oils. Equipment for making such measurements, designed especially to insure accuracy and to obviate some of the difficulties commonly experienced, is described in this issue (*pages 264–8*).

VACATION plans soon will be made by many Institute members. Why not be one one of those to combine a vacation trip with attendance at the A.I.E.E. 1936 summer convention to be held at Pasadena, Calif.? Special transportation facilities are contemplated for eastern members (*page 304*).

HEAVISIDE'S operational method of circuit analysis has proved to be a useful tool in the study of traveling waves; in a paper in this issue, this method is applied to the study and theory of transients arising from the sudden application of sinusoidal potential to a transmission line (*pages 245–51*).

WHAT type of highway vehicle may be constructed that will embody the maximum number of respective good points of trolley car, trolley coach, and motor bus? The answer of one large eastern transport company to this question is the "all-service" vehicle (*pages 236–40*).

DISCUSSIONS in this issue include a few remaining closures of 1935 summer convention papers, remaining discussions of 1935 Pacific Coast convention papers, and complete discussions of papers presented at the Oklahoma District meeting (*pages 269–96*).

ELECTROCHEMICAL industries in Japan are said to have progressed rapidly during recent years. The total annual value of the products of these industries has been estimated to be nearly $90,000,000 (*pages 252–4*).

A SPECIAL unannounced feature of the Institute's recent winter convention was an explanation of the major disturbance that occurred on the system of the New York Edison Company on January 15, 1936 (*pages 307–8*).

NOMINATIONS for Institute offices for the year 1936–37 were announced recently by the national nominating committee (*pages 306*). Biographical sketches of the nominees also are given in this issue (*pages 311–13*).

CANDID camera studies of some of the attendants at the Institute's 1936 winter convention reveal interesting and varied personalities (*pages 304–05*).

NORTH Eastern District meeting to be held May 6–8, 1936, New Haven, Conn., will feature a variety of subjects and inspection trips (*pages 304 and 306*).

AMERICAN Engineering Council will carry on its activities during 1936 with committees divided into 4 general groups (*pages 309–10*).

Anniversaries

—A Message From the President

"BEHOLD! I make all things new," is a phrase that may be reverently appropriated to describe the effect of the successful electrical inventions of the last 50 years.

Never was there keener interest than today in history—racial, individual, political, industrial—and never was there an epoch or era upon which hereafter the attention of mankind will center more than that to which we now refer. It is our privilege to deal with the electrical part of the story and with the men who had such a large part in it on this, their so-termed fiftieth anniversary. The story of electricity is one which is constantly unfolding. Generally speaking, only the first pages have been turned. History is being made with each day of each year, and as time progresses the electrical phase of our existence is occupying a more important place.

To the urban world of the 1880's the practical usefulness of electric energy was considered a certainty; but out of this certainty there arose 3 new uncertainties. In the first place, what was electricity's use to be? Second, which was the better form in which to generate it, direct or alternating current? Third, how might it be efficiently transmitted?

The first of these questions had begun to be answered by Edison and Sprague. But there remained the second and third questions: In what form, and how, was electricity to be generated and transmitted for use? These questions first resolved themselves down to whether alternating current or direct current was the more advantageous. This resulted in a long and bitter scientific quarrel with Edison in the United States and the great Lord Kelvin in England leading the fight for direct current, in opposition to men like Elihu Thomson and Nikola Tesla, in the United States, who believed in alternating current. Only within comparatively recent years did electrical engineers definitely realize that in developing a dynamo to generate only direct current, they had been in the mistaken mood of throwing away the meat of the cocoanut and eating the shell, and there were good reasons why this was not at first apparent. Early motors would not run on alternating current. The important work of electroplating could not and never will be performed by alternating current. It will not charge a storage battery.

Yet alternating current did have enormous advantages even before the days of appliances that will run on nothing else. In many ways it was Elihu Thomson who made them recognized. It was Thomson who raised a humble voice against Lord Kelvin in the fight for alternating current machinery. It was he, also, who in 1879, developed the so-called 3-coil dynamo for lighting electric lamps—a direct current machine, but one which shortly thereafter led the way toward alternating current dynamos and motors—and who followed this splendid achievement with the so-called "repulsion motor," a cousin to the single phase induction motor. It was Nikola Tesla who advanced the battle upon still another front—that of a brushless motor which, of course, depended upon alternating current and which he patented in the United States in 1888.

Shortly before, Tesla had made 2 important associations—with Thomas A. Edison and with George Westinghouse. The latter was the more important in view of Tesla's intense interest in the application of alternating current, for it was Westinghouse who, in large measure, brought to the United States the solution to electricity's third riddle—the riddle of efficient transmission. Here was a difficult matter, the answer to which happily lay in an experiment Michael Faraday had performed in the year 1831. No practical electrical engineer had found much use for this observation until, in 1884, the Frenchman Gaulard and the Englishman Gibbs instituted the "secondary generator" now known as a transformer. This discovery was important not only for itself but for the interest it aroused in the mind of George Westinghouse who had seen the results. Westinghouse hurried back to the United States and with a brilliant young engineer by the name of William Stanley, Jr., tackled the problem of efficient electrical transmission. It was Stanley, who, in 1885, at Great Barrington, Massachusetts, built an experimental installation and saw that it was possible to transmit power efficiently over relatively long distances by stepping the voltage up at the generator end of the line and stepping it down again at the load end.

Ground then was broken for the great transmission lines of the future, and Charles P. Steinmetz had a foundation upon which to rear his intricate theories of alternating current generation and transmission.

Other men of this period, among whom were Sprague, Stillwell, and Lamme, made important contributions to this new field of electricity, but it is generally conceded that Stanley was one of the most prominent among the electrical inventors and engineers who made long distance electric power transmission possible. His inventions on the transformer and his early work in the development of the alternating current system contributed greatly to the advancement of the electrical art.

In commemorating the 50 year anniversary of the first successful transmission of alternating current for lighting and power purposes it is of interest to recall a number of other incidents that occurred during the year 1886. Among these were the first successfully marketed adding machine, the first practical phonograph, the successful commercial operation of the first electric street railway, the first typewriter ribbon. Also Elihu Thomson patented the electric welding process.

One might go through a long list of early pioneers whose abiding faith in the significance and importance of electrical applications has done so much to advance our national industrial progress. It has been largely through their broad vision, energy, and engineering and commercial sagacity that light and power service has been advanced from its very beginning to the place it now holds as one of the most important factors in the sum of human happiness, comfort, and achievement.

Early History of the A-C System in America

By C. C. CHESNEY
President A.I.E.E. 1926–27

CHAS. F. SCOTT
President A.I.E.E. 1902–03

Significance of Alternating Current

THE outstanding place which electric power occupies in our modern life has been attained through the use of alternating current. Hence the celebration of the fiftieth anniversary of its introduction in America recounts more than an episode in engineering development—it points to the beginning of a utilization of electric service which marks a new era in our industrial, economic, and social life.

In larger perspective, steam power direct from Watt's engine created nineteenth century transportation and an industrial revolution, but in the twentieth century it becomes many times more effective through electric transmission and conversion into light and heat and motor power.

The pioneer ideas and apparatus of a half century ago are significant because of what evolved from them. A review of the state of the art when alternating current began, and its subsequent progress, reveals a marvelous story of engineering achievement; while a recital of electric service today brings into clear focus the supreme function of electricity in amplifying the usefulness of power.

For the development of electrical service in which it has led the world, the United States is fundamentally indebted to 2 men: George Westinghouse through his vision and commercial enterprise, and William Stanley through his genius and persistent effort under conditions of extraordinary difficulty. Each received the Edison medal awarded by the American Institute of Electrical Engineers, for his contribution to the alternating current development. Others both here and abroad contributed, but through the association of these 2 men there were provided the impetus and the facilities that produced the result.

It is a story of romance and of wonder: how crude apparatus in a simple demonstration in 1886 by William Stanley in Great Barrington, Mass., through its commercial exploitation by George Westinghouse, soon led to extending electric light as a luxury; then—within a generation—to providing a universal necessity.

However, the early advocates of the alternating current system had much opposition. Technical problems were many and obscure. Opposition from the scientific and engineering world ranged from incredulity to the most vicious and vigorous condemnation by the exponents of the direct current system then in use.

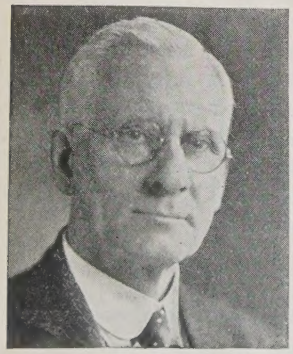
The 2 most distinguished electrical engineers of Europe and America at that time, Sir William Thomson and Thomas A. Edison, were outspoken in condemnation of the alternating current system.

In the November 1889 issue of the *North American Review*, Thomas A. Edison, in voicing his disapproval, stated: "There is no plea which will justify the use of high tension and alternating current, in either a scientific or commercial sense—my personal desire would be to prohibit entirely the use of alternating currents. They are unnecessary, as they are dangerous." Sir William Thomson (Lord Kelvin), president of the International Niagara Commission, outstanding advocate of direct current among those

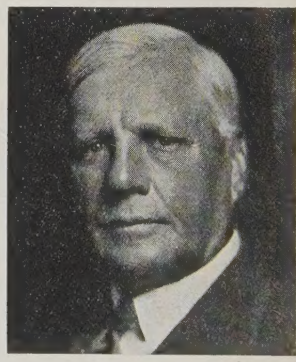
As part of the Institute's celebration of the fiftieth anniversary of the establishment of the alternating-current system in America, which is being carried out under the auspices of a special committee,* this brief story of the inception and early history of the alternating current system has been prepared by 2 past-presidents of the Institute, both of whom were actively identified with the early development of the system, and both of whom have made many important contributions to the development and application of alternating current power. It is a story of achievement against the strenuous opposition of many prominent electrical engineers of that time. The present almost universal use of alternating current in the great electric power systems of today is in itself a fitting tribute to the genius and vision of George Westinghouse and William Stanley who, through their long and persistent efforts under extraordinary difficulties established the first alternating current system in America on March 20, 1886.

*Committee on celebration of fiftieth anniversary of establishment of alternating current system in America, A. W. Berresford (A'94, M'06, F'14, member for life and past-president) chairman.

Chas. F. Scott



C. C. Chesney



associated as technical advisors in the Niagara enterprise, cabled on May 1, 1883, as final decisions were about to be made: "Trust you avoid gigantic mistake of adoption of alternating current."

But in spite of every possible legal and engineering opposition, the alternating current system made rapid progress. It was a case of the survival of the fittest, and the alternating current system as developed by William Stanley and George Westinghouse in their complementary relations triumphed.

These facts are related here only to emphasize the undeveloped state of the art of that early period, and to indicate how limited and provincial was its outlook compared with present accomplishments.

Historic Periods of Electric Service

Direct Current Only

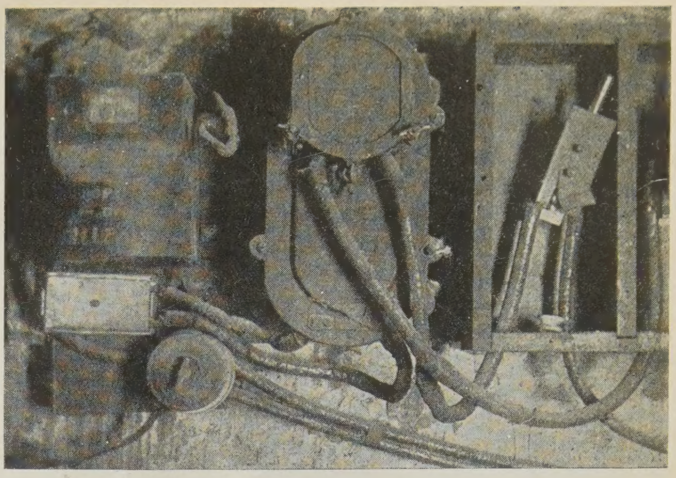
Electroplating was the first important industrial use of electric current. Public service began with street lighting by arc lamps, which in the early eighties were becoming common in most cities and towns. Each direct current arc machine supplied a constant current to from 15 to 50 or more lamps connected in series. Incandescent lamps of nominally 100 volts were operated by direct current from isolated plants in hotels and stores; the pioneer central station was Edison's Pearl Street Station in New York City (September 4, 1882). The serious limitation was distance. The 3-wire direct-current system was not commercially practical beyond a radius of $^1/_2$ to $^3/_4$-mile, because of the excessive cost of the copper conductors. Service therefore was limited to the centers of cities. Outlying residential districts were not served, nor was central station power for motors available in quantities to make it a factor in industrial operations.

Alternating Current

Single Phase Alternating Current—Many Systems. In 1886 the alternating current transformer system extended the radius for incandescent lighting at first to a few miles, and then to much greater distances. Small wires carried a small current to the customer's premises, where it was "transformed" to a large current (coincident with change from high voltage to low voltage) for operating lamps. The significant feature was the transformer.

In this period there were many "systems." A typical central station might include many engine-driven arc-light machines, each with its own independent circuit; direct current generators supplying nearby incandescent lamps; 500-volt generators for street railways; and alternators for remote lighting. Large cities had a dozen or more stations, each supplying one or more kinds of service.

Polyphase Alternating Current. Inaugurated commercially in 1893 at the World's Fair, and on a large scale at Niagara in 1895, the polyphase system came into extended use during the nineties of the past century. Not only did it provide for operation of induction motors, but it led to a radical revision of electrical methods. Polyphase generators could be made of greater capacity; they were better suited to operation in parallel in the same or in remote stations; they were adapted to turbogenerator speeds and outputs; the polyphase system was adapted to high voltage, to long distance transmission, and to supplying through substations direct current as well as alternating current. All types of electric service were then available from a single power generating unit which could operate with others in "superpower" systems or networks. Thus equipped, electric power extended in use some thirtyfold in the 30 years beginning in 1900.

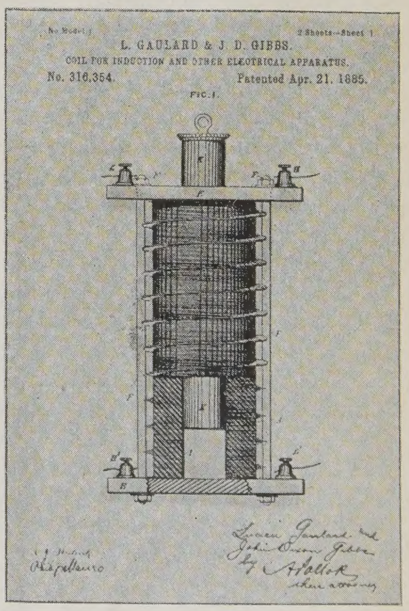


40-light 1,000-volt transformer with an early Shallenberger meter; an old installation found still in service just a few years ago in the basement of a Sixth Avenue store in New York City

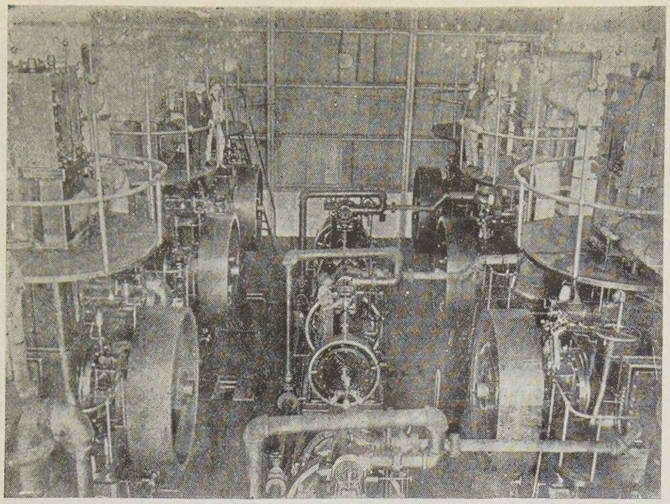
Commercial Beginning of Alternating Current in 1886

Commercial alternating current distribution in America in all probability was derived by evolution from the English Gaulard and Gibbs system with transformers connected in series.

An installation of this type was exhibited at the



Reproduction of a patent drawing of the original Gaulard and Gibbs transformer that was registered in the United States, and to which George Westinghouse had secured all rights



Interior view of the main engine room of the United Electric Light and Power Company's 29th Street and First Avenue generating station

The engines were double-acting steeple-compound units, 2 of which were used originally at the 1893 World's Fair in Chicago, Ill.; at the close of the fair they were rebuilt and installed in this station, where they were direct-connected to 60 cycle polyphase generators

Turin Exhibition in 1884, and there were other installations in Italy and England. This system, however, did not prove to be practical as a general system, since owing to the units being connected in series, the regulation was not satisfactory, and the voltage distribution was disturbed seriously whenever a customer was switched on or off, the more so as the transformers employed were of very imperfect design and construction.

Knowledge of the Gaulard and Gibbs system reached George Westinghouse in the spring of 1885. He was interested in developing new enterprises, so he secured options on Gaulard and Gibbs patents; and in January or February 1886, Franklin Pope negotiated for Westinghouse the purchase of the patent rights for the United States.

George Westinghouse secured apparatus for test, several of the "secondary generators" (transformers) and a Siemens alternator, which arrived at Pittsburgh about September 1, 1885.

Westinghouse had in his employ at the time a young inventor of a self-regulating dynamo and of incandescent lamps, William Stanley. O. B. Shallenberger, the inventor of the integrating meter, was on the staff. Stanley took keen interest in the Gaulard and Gibbs project.

In September 1883, at Englewood, N. J., prior to his association with Westinghouse, Stanley noted and discovered the counter electromotive force set up in an induction coil during its excitation by an alternating current. He says: "I believe that I first coined the word 'counter' electromotive force."

In February 1884, Stanley became associated with Westinghouse, as previously stated, directing his activities toward the development of direct current machinery and systems, as well as incandescent lamps, which Westinghouse was putting on the market.

In the spring of 1885, Stanley took up actively again the alternating current problems which he more or less had studied in 1883. In September 1885, when some of the Gaulard and Gibbs apparatus and the Siemens alternator had reached Pittsburgh, his theories quickly developed into concrete form. He now had apparatus and alternating current for use in tests. His alert and fertile mind soon focused on 2 fundamental features, the system and the device. He rejected the Gaulard and Gibbs plan of operating the primaries in series by a constant current (after the method of operating arc lamps) and chose the method of parallel connection to a constant potential primary circuit. He was not alarmed at the idea of connecting a coil of a few ohms resistance to an alternating current circuit of several hundred volts, as his study of the subject convinced him that by proper design the counter electromotive force would sufficiently limit the current, and furthermore that current in the secondary winding would reduce the counter electromotive force so that the primary current would vary with the secondary load.

To meet these ideal conditions he altered the construction of the "transformer." In the Gaulard and Gibbs device the primary coil had but few turns (usually the same as the secondary), and the core of iron wires was slim and long and in some constructions was a straight core and not a complete ring. Stanley made transformers with many primary turns, some "with iron wire cores in the form of a ring," while others he says "had continuous and laminated cores." He recounts satisfactory laboratory tests of his experimental transformers embodying these features during the latter part of September 1885.

Two months later Stanley prepared a "Specification for Induction Patent," claiming a system in which parallel connected transformers exert a counter electromotive force sufficient practically to obstruct the flow of current, and which "shall vary with secondary load," and embodying a closed magnetic core. He later wrote that the features of low magnetic resistance producing a high counter electromotive force so that "no current flows" and acting as "a frictionless vehicle to transfer all the lines of force from the primary to the secondary circuit without loss in transmission" were 2 points which "have never to my knowledge been demonstrated outside of my work." Thus, according to Stanley's own testimony he developed a transformer and a transformer system which he tested in the Westinghouse shops in Pittsburgh, Pa., in its entirety prior to September 29, 1885.

This system of Stanley's subsequently was tested in Pittsburgh by Reginald Belfield, an engineer of the Gaulard and Gibbs Company who arrived at Pittsburgh from England about November 23, 1885. Belfield testified later that he rated the Stanley converters of high value, cheaper to build, smaller in size, and more generally useful for electric lighting (than the Gaulard and Gibbs apparatus).

At the National Exhibition in Budapest, opened May 1, 1885, the firm of Ganz and Company presented a new system designed by Zippernowski, Deri, and Blathy, in which transformers operated in

parallel from a constant potential circuit. This system was also exhibited at an exposition in London in the summer of 1885, and had been seen by Belfield. Stanley testified in 1888 that he had no information in regard to this system prior to September 29, 1885.

The December 1885 conferences on, and the tests of, the new transformers and system of Stanley's at Pittsburgh were constructive and convincing. Westinghouse quickly grasped the salient points of the apparatus and suggested improved methods of construction, such as the H shaped punching (which replaced 3 strips); the coils surrounded the middle section of the punching after which the coils were completely enclosed by 2 supplementary strips. This subsequently was improved by Stanley's E plate with one detached strip laid alongside, and this was improved further by Schmid, another Westinghouse employee, who made a complete plate in one piece, slotted so that by bending the extensions the central tongue could be slipped through the opening in the coils. In modern transformer building, however, all formed plates have been superseded by the simpler straight strip and L shaped punching.

Following the tests and discussions in Pittsburgh after Belfield's arrival, Stanley said that the system should have intensive experimental development, and that he would like to undertake it at his old home in Great Barrington. His health was frail, and he preferred living among the Berkshire hills instead of among the Pittsburgh mills. Belfield joined Stanley in Great Barrington on January 5, 1886.

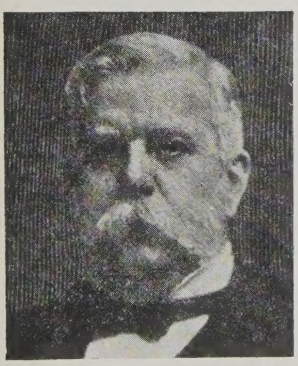
Westinghouse organized the Westinghouse Electric Company, the charter for which was granted January 8, 1886, and the practical organization was completed March 8, 1886. The capital stock was $1,000,000.

In the early fall of 1885, Stanley had opened a laboratory in an old rubber mill at Great Barrington, in which later he installed the Siemens alternator sent him by Westinghouse. A half dozen transformers made in Pittsburgh in December and January were supplemented by a score of others manufactured in the rubber mill laboratory. These were made by hand, with several improvements introduced in the course of manufacture, and there were no exact duplicates.

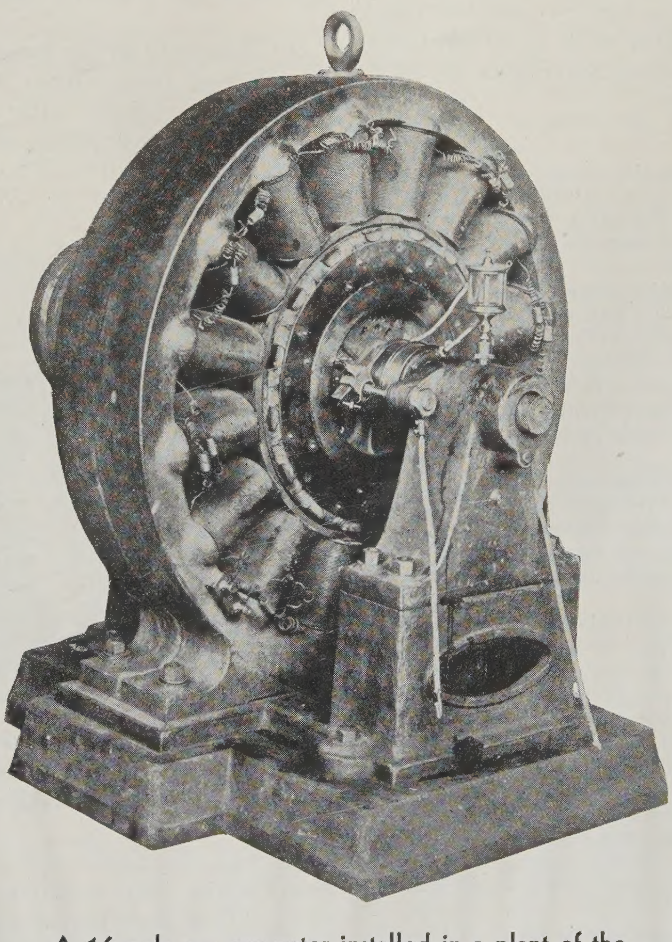
Stanley stated a few years later: "The object of my investigations in Great Barrington on converters (transformers) was to acquire accurate data respecting the length of wire, weight of iron, and structural shape of converters, limited by consideration of cost on one hand and commercial efficiency on the other"—in short, to find the most economical proportions to build converters.

At first, iron plates of about $^1/_8$ inch in thickness were tried. The thin iron used by photographers for making tintypes was found to work well, and the local supply was about exhausted in transformer construction. The plates were insulated with thin paper.

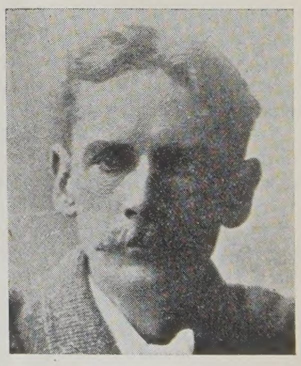
On March 17, 1886, Stanley reported to Westinghouse that "the lamps in my cousin's store were running last night." A week later the local newspaper reported the supplying of lights to several stores on Main Street on March 20. Operation continued in this demonstration plant, which lighted a score of houses and stores with the equivalent of 200 16-candlepower lamps, until the sudden demise of the 500 volt generator on June 17, which considerately was attributed to a misplaced screw driver. Westinghouse, with others, had visited the plant in April, and was convinced of its importance. Stanley had



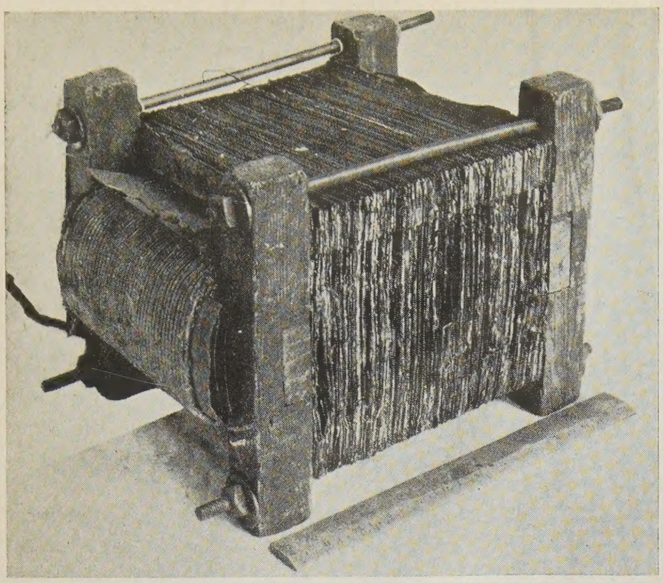
George Westinghouse



A 16-pole a-c generator installed in a plant of the Brush Electric Light Company, Buffalo, N. Y., on November 30, 1886. The design was the work of Stanley, Shallenberger, and Schmid



William Stanley



The "induction coil" or transformer designed by William Stanley in the fall of 1885. It was wound for 500 volts primary, 100 volts secondary

much to contend with in demonstrating the merit of his alternating current system of distribution, as indicated in the following extracts from a letter of H. M. Byllesby, later a very prominent figure in the public utility field, written to T. C. Martin, former editor of *Electrical World*, on November 25, 1922. We quote:

"Dear Mr. Martin:

"In those days Stanley had taken up his residence at Great Barrington, Mass., where he was equipped with a laboratory, and where he installed the first real alternating current plant in the United States and put in operation, which was about February or March 1886.

"It had been found prior to my taking charge of the Westinghouse Electric that Stanley's best work was done away from contact with the every day, never ending mental work, discipline, and industry of either the main office of the shops, or the working laboratory at Pittsburgh, and so in the earlier days of the alternating current, Stanley was established with a residence at Great Barrington, Mass.

"When I joined the ranks of the Westinghouse Electric Company there was substantially no one in the organization, excepting Mr. Westinghouse himself and dear old Frank Pope, who had any real expectation of anything commercial coming out of the alternating current system.

"I had known Stanley for several years prior to joining Mr. Westinghouse's interests. There was a mutual liking between us, and sometime in February or March 1886, when I was busy developing the direct current apparatus for the then Westinghouse Electric, and making sales which for those days were of rather unusual importance, Stanley came down to see me at New York on a Friday and impressed me with the fact that he actually did have a small alternating current station running at Great Barrington, that he could receive no audience from any of his associates in the company and that he pathetically implored me to go back to Great Barrington with him and look at it.

"This I did, and spent the following Saturday there. I found he had a complete system, barring of course the meter and the motor, that it was actually performing, and performing well, and with relatively slight modification could be put upon the market.

"I returned to Pittsburgh and reported to Mr. Westinghouse and my associates. I was enthusiastic to the last degree. All of them, even Mr. Westinghouse, were somewhat skeptical, but we immediately had a thorough examination made, which resulting in proving that the alternating current system had arrived successfully.

"******and to my surprise Mr. Westinghouse placed me in full charge as vice president and general manager of the company, this was on July 1, 1886.

"From that time forward we progressed with amazing speed and on about the 6th of September 1886, we had completed and had running 2 alternating current machines of the joint design of Stanley, Shallenberger, Albert Schmid, and myself.

"Each of these machines had a capacity of 750 lights, as then rated. They were driven by Westinghouse engines, located in the erecting shop in Duquesne Alley, and their output was transmitted over a transmission line borrowed from the Allegheny County Electric Light Company, to 2 residences which we rented for that purpose in what was called Lawrenceville, Pittsburgh, a distance from the generating units of about $2^1/_2$ to 3 miles.

"In each of the residences we installed banks of . . . lamps, and we kept this plant running continuously for a period of several weeks; and immediately thereafter started selling plants throughout the country.

"Incidentally, one of these residences—and the lights were kept running night and day—was in charge of L. B. Stillwell, who had come into the organization through an acquaintanceship with myself, about 3 weeks prior to that time.

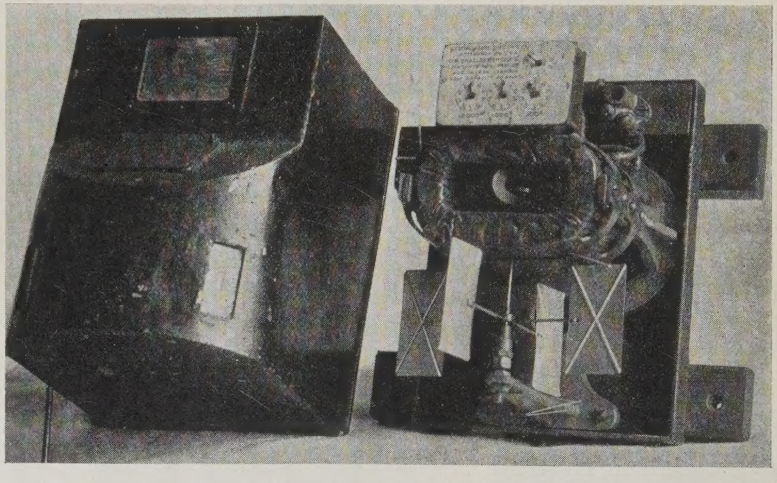
"Mr. Westinghouse had been absent practically from the time that I was installed as vice president and general manager of the electric company on July 1, 1886, until we had run successfully on this Lawrenceville plant for about 10 days.

"I had wired him at Quebec where he was staying with his family, of the success, and he immediately returned home.

(Signed) H. M. Byllesby"

Commercial Service Inaugurated Nov. 1886

As indicated in the foregoing letter, activities were transferred from Great Barrington to Pittsburgh. The single phase alternator for which Stanley furnished the drawing had a smooth cylindrical armature with wires laid on the surface and held by band wires—the armature rotated in a multipolar field. Transformers according to the Stanley pattern also were designed for manufacture; the electrical features by Shallenberger, who had participated in tests and discussions with Stanley; and the mechanical features by Albert Schmid.



Induction type ampere-hour meter, the first a-c integrating meter and the parent of all a-c watt-hour meters now in use, invented by Shallenberger in 1888

The supplemental tests with the new apparatus, employing the circuit several miles from the Westinghouse factory to Lawrenceville, were followed by commercial installations. The first plant began operation November 30, 1886 at Buffalo, New York, only a year and 4 days after Stanley completed his "Specification for Induction Patent." The plant at Greensburg, Pa., began operation soon afterward, although its apparatus had been shipped first. In the following October Shallenberger stated that between 30 and 40 plants were in operation. These were all of the 133-cycle 1000-volt type. No other fact so aptly illustrates the importance of the development—its completeness, and the existing need—than this exceeding rapidity in development.

NOTE: The foregoing story of the transformer in 1885–1886 is the understanding of the authors after recourse to various statements and records, most of which dealt with particular incidents or phases of the development. The statements made are based largely upon testimony given in 1888–1889 in a patent interference between Slattery and Stanley, in which Stanley was successful.

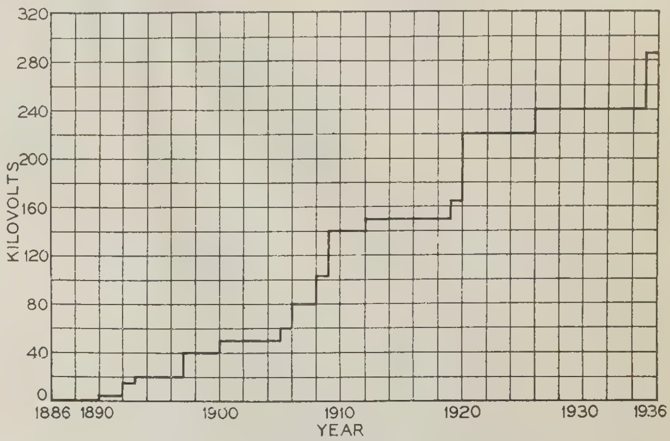
Appendix

SUPPLEMENTARY STATEMENT—BY CHAS. F. SCOTT

I owe much to Stanley for his lucid paper on alternating current phenomena ("Phenomena of Retardation in the Induction Coil," A.I.E.E. TRANSACTIONS, January 1888, pages 3–14). My acquaintance with him, followed by lifelong friendship, began in October 1888 when I assisted in tests on an experimental machine which he brought to Pittsburgh. A short time prior to his death, Stanley wrote me that he felt that his part in the early drama was not understood. Upon invitation, I spent 2 days in Great Barrington, during which time Stanley showed me the old rubber mill and the location of the houses that were lighted. He told of his proposal to Westinghouse in December 1885 that he take up the problem of intensive development in Great Barrington. He wanted to embody in actual apparatus his theory of transformer action, and to demonstrate an operating system. There were difficulties aplenty. Shop facilities were meagre; materials were hard to get; his health was erratic; speed regulation of engines and voltage regulation of alternators were atrocious. It was a pioneer adventure, with little of theory or precedent to guide, and he took pride and satisfaction in having brought forth a successful result. He hoped that occasion might come to tell his story to the American Institute of Electrical Engineers. This is the opportunity.

SUPPLEMENTARY PIONEER DEVELOPMENTS —BY C. C. CHESNEY

The Niagara Falls-Buffalo 23-mile transmission was established in November 1896, at 11,000 volts between conductors, which some 4 years later was increased to 22,000. It had followed quickly on the heels of the great Frankfort-on-Mein electrical exposition, held in Germany in 1891, with its progressive demonstration of a 100-mile 3-phase power transmission from a waterfall at Lauffen to the exposition. The brief years that intervened between the Frankfort Exposition and the World's Fair witnessed the great economic-technical battles of the phases, 3-phase versus 2-phase, and of the frequencies. The controversy invaded the counsels of the Niagara Falls-Buffalo power transmission development, when suddenly the contest was stopped, so far as Niagara Falls development was concerned, by Scott's invention of the T connection for transformers to convert 2-phase to 3-phase circuit in balanced power relation.



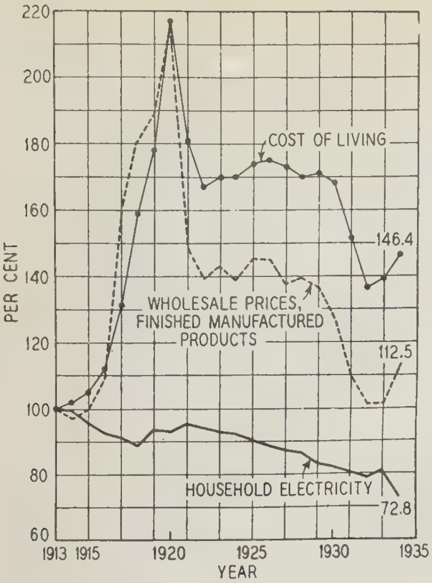
50 years' trend of approximate transmission potentials in America, 1886–1936

With the growth of the electrical industry came the development of transformers for higher and higher voltages. On the knowledge of this development, the transmission voltages of the then projected great power companies of California, the Standard Electric and the Bay Counties Companies, were fixed at 50,000 and 60,000 volts, respectively.

These latter voltages enabled these companies to deliver power so successfully to regions widely separated from its source that the extension of the possible territorial limits coverable by the alternating current system was purely a function of the apparatus made available by further engineering developments.

The value of the tremendous power stored in the mountain streams of California, and for that matter of the world, was passively realized, but it was the work of these 2 utilities that first demonstrated the technical feasibility of the conversion and transmission by means of alternating current, of any amount of such water power any distance, controlled only by the usual commercial and financial limitations.

It is well known, and has been stated many times, that a discovery in science is not an isolated event. The laws of nature have ordained that progress or change is never by leaps or revolutions. This, of course, is true of electrical engineering, and that branch of it, the long distance transmission of power by means of alternating current. It has grown, as does the snowball, by the process of almost infini-



Comparison of the price of electricity with the cost of living and with the prices of manufactured products, 1913–34

The figures on which these curves are based were computed by the United States Bureau of Labor Statistics and furnished by the National Industrial Conference Board

tesimal additions. Practically every experiment or new development in the generation, transmission, and conversion of electric power is a modification of an experiment that has gone before. Almost every new theory is built through the contributions of many workers, of many different elements—one adding a little here and another a little there—so that to the observer in retrospect the progress seems to have been continuous and uniform.

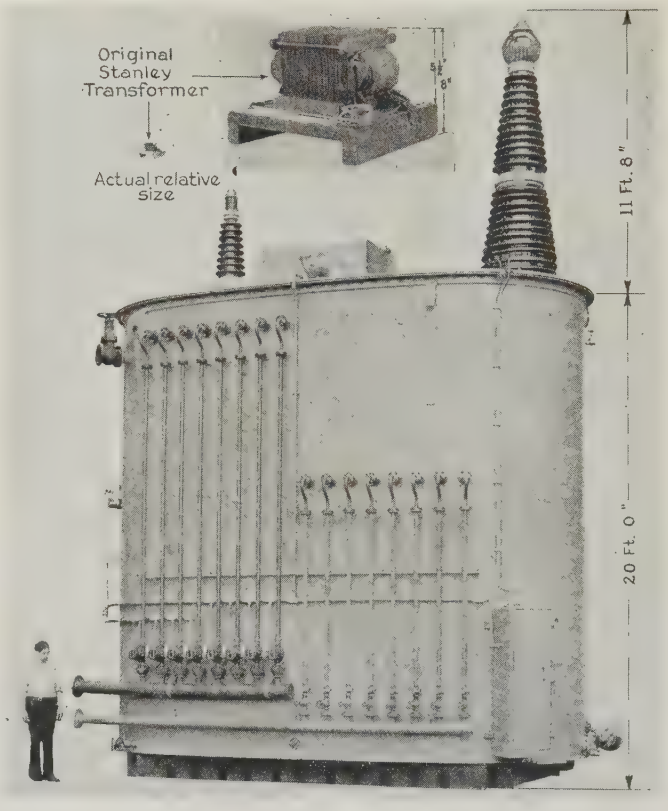
The changes introduced into the art during the past century by the engineers of that period have placed the whole structure of the electrical art of today, as applied to light and power, firmly on the use of alternating current. It has made economically possible the generation of large amounts of power in suitably located central stations, and its conversion and transmission to those points where it can be used most advantageously by industry to operate and to increase the capacity and the economy of mills and factories; to provide electric transportation for the town and country; to extend and to improve the processes of mining and metallurgy; and now to place in the homes of the great agricultural class, through the use of electric power, the comforts and conveniences of the city, and to place in the hands of the farmer the opportunity to extend broadly the economy of the farm to a point at which it may compare favorably in efficiency and productiveness with the factory and workshop.

The effect of the introduction of the alternating current system on the economic conditions within the nation is shown by the fact that of all elements entering into the living cost of the average man, the cost of electricity is the one factor that has shown a substantially continuous decline. It now approximates but $^3/_4$ of its cost in 1913–14, while general living cost has *increased* nearly $^1/_2$ in the same period.

These contributions by practical engineering to the world's affairs have been progressive in character, and have been directed toward the one ultimate purpose of all science and engineering—the improvement of human conditions, and an endeavor to bring into the world an era of more gracious living.

The invention of the integrating meter by Oliver Shallenberger was vital and immediately important in the growth of the electrical industry. Until the invention of this instrument and much needed device, there was no instrument to measure the quantity of alternating current supplied to the consumer. While the meter operated on the same fundamental principles as the Tesla motor, Shallenberger invented the meter independently of Tesla.

The super-voltage transformer was practically impossible without oil. Professor Elihu Thomson introduced its use commercially, but the idea was not new, as the use of oil for insulating induction apparatus was patented by David Brooks of Philadelphia in 1878.



Comparison of original transformer built in 1886 by William Stanley and one of the transformers built in 1935 for use on the Boulder Dam-Los Angeles transmission line

Stanley's Great Barrington plant demonstrated for the first time in America how electric power could be generated at a low voltage, transformed to a higher voltage, retransformed to a lower voltage, and used at this voltage as might be required. This feature of adapting the voltage to varying requirements and of maintaining it substantially constant, irrespective of the load, rendered possible the enormous development and progress in the distribution and transmission of electric energy that have taken place.

This capability of voltage transformation lies in the transformer itself, insignificant though it always has appeared. Stanley always spoke of the transformer as the "heart of the alternating current

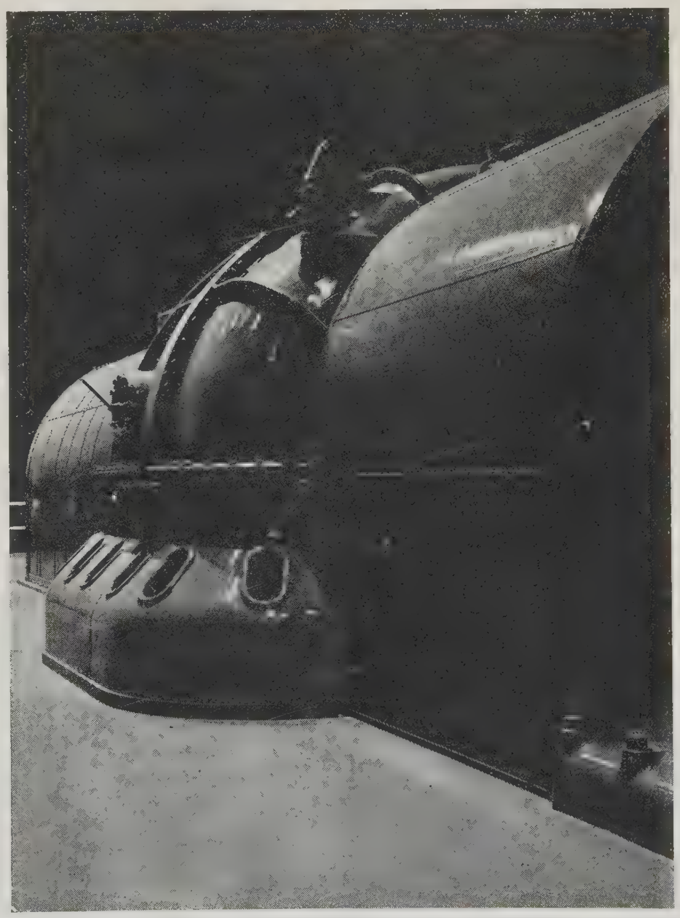
system." Naturally, the great development of the art has been accompanied by a similar development of the transformer.

Very early, Stanley had visualized properly the fundamentals of the transformer design, and correctly solved many of the problems in the Great Barrington installation. This revealed a thorough understanding on his part, of electromagnetic induction—surprising for 50 years ago.

The same ability in handling these laws as applied to transformers was shown by Stanley in the construction of the inductor alternator, which had no windings on the rotor, a feature considered of much value at the time. The inductor alternator, as well as the Stanley induction meter, did not survive; but the transformer did, and is substantially the same as the one originally built by Stanley.

At 30 years of age, Stanley had a full conception of the alternating current station idea of manufacturing power, that is, the manufacture of power in some suitable location, transmitting and distributing it to points of consumption by the use of alternating current. With this idea fixed in his mind, and fully determined to find at Pittsfield, Mass., whether there were any limits in sight barring the use of potentials higher than 2,000 volts, then generally employed, he instructed his associate to design and build transformers and line for 15,000 volt operation. To this end a pole line was erected in 1892, and a transformer house built and set up with transformers. These increased the potential of the town circuit from 1,000 volts to 15,000 volts. The line was connected to this potential supply, the current sent around a farm and back to the same transformer house, then the line potential retransformed to 1,000 volts, and the distribution transformers of the local company operated. This little plant was operated during the New England winter with entire success, and the engineering data obtained were the reason for subsequent recommendation by the Stanley Electric Manufacturing Company for use of potentials of higher than 15,000 volts.

The Stanley Electric Manufacturing Company, organized in 1891, later became the Pittsfield Works of the General Electric Company.



Editor's Note: In addition to the wealth of historical information given in the foregoing Scott-Chesney article, there is additional information of a similar nature contained in the texts of the Edison Medal addresses delivered during the recent winter convention upon the occasion of the award of the 1935 Edison Medal to Dr. Lewis B. Stillwell. These addresses are published in the news section of this issue of ELECTRICAL ENGINEERING.

For the convenience of those wishing to pursue further this subject of electrical history, the following list of selected references is offered:

1. ELECTRICAL ENGINEERING, v. 53, May 1934. In this 50th anniversary issue appear many data collected first hand from many authoritative sources and pertaining to the early history and continued development of the alternating current system.

2. *Electrical Review*, v. 40, Feb. 15, 1902. Beginning on page 223 of this, the 20th anniversary issue of the publication, is William Stanley's own account of some of his pioneering work on the alternating current system, appearing under the heading "The Beginning of Alternating Current Engineering." Also in this issue is a series of articles contrasting the status of the electrical development of that time to the status at the time of the establishment of the publication 20 years before. Several portraits of men then prominent in the development of electrical arts and trades also are shown.

3. THE WESTINGHOUSE CONVERTERS AND OVERHEAD SYSTEM. *Electrical World*, v. 10, 1887, p. 65. A brief illustrated description of the Westinghouse converters (transformers) and alternating current system of distribution.

4. REPORT OF N.E.L.A. COMMITTEE ON ELECTRICAL DISTRIBUTION BY ALTERNATING CURRENTS. *Elec. World*, v. 10, 1887, p. 92–3. A report on the status of alternating current distribution at that time, and an account of some of the difficulties encountered. (Report read by Slattery who had a patent interference with Stanley.)

5. *Electrical Review*, v. 38, Jan. 12, 1901. This issue contains a group of illustrated articles outlining the history of electricity and its applications up to that time, and includes a series of portraits of men who had contributed to the progress of the art in the 19th century.

6. PITTSFIELD SECTION, A.I.E.E. ANNIVERSARY DINNER. *Electrical Review and Western Electrician*, v. 58, 1911, p. 926. This is an account of the fourth annual dinner of the A.I.E.E. Pittsfield Section, commemorating the 25th anniversary of the first commercial application of the transformer and alternating current generator in America. William Stanley was the guest of honor, and the meeting was featured by addresses by several well known Institute members. A brief account of the meeting was published in the A.I.E.E. PROC., v. 30, 1911, p. 191.

7. SPEECHES AT THE A.I.E.E. ANNUAL BANQUET. A.I.E.E. PROC., v. 31, 1912, p. 321–37. A complete account of the 1912 annual banquet of the A.I.E.E. held during the convention at Boston, Mass., and at which the 1911 Edison Medal was presented to George Westinghouse.

8. A.I.E.E. PROC., v. 32, 1913, p. 304–05. A brief account of the ceremony of presentation of the 1912 Edison Medal to William Stanley.

Development of the All-Service Vehicle

The question in the minds of many transportation men today is: "What type of highway vehicle may be constructed that will embody the maximum number of respective good points of trolley car, trolley coach, and motor bus?" The answer of one large eastern transport company to this question is the "all-service" vehicle, a combination trolley coach and gasoline-electric motor bus. The principal items of interest in a highway vehicle are performance, rider appeal, operating economy, and construction. As to performance, it appears that much yet may be accomplished. Recent experiments indicate the importance of the contribution that can be made by the electrical engineer to developments in this field.

By
MARTIN SCHREIBER
ASSOCIATE A.I.E.E.

Public Service Coordinated Transport, Newark, N. J.

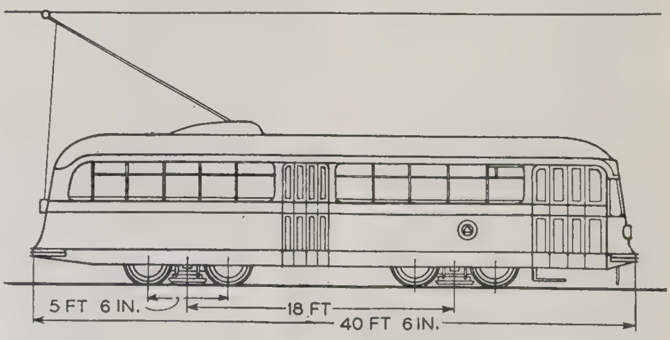
When the ordinary street car turns a curve on rails, with, say, a 50 foot inside radius, it is necessary for the wheels on one side to slip approximately 7 feet. There are numerous street railway lines of approximately 5 miles in length that have as many as 15 curves, which means 105 feet of wheel slippage for the route. This results in 3 disadvantages: reduction in efficiency due to friction of dragging steel wheels over steel rails; excessive wear on wheels, rails, and special work; and disagreeable noise. One often hears this squealing and grinding when a train of cars is rounding a curve.

The electrical engineer is the logical one to rectify the rigid wheel and axle; he certainly has the means to do it with electrical power, which is the most economical in generation, distribution, and application known. Then, why should the rail car depend entirely on steel springs and solid rubber to furnish a comfortable ride? In this, why not take a leaf from the book of the automotive engineer who perhaps took the battery, generator, starter motor, and ignition from the electrical industry? The principle of the pneumatic tire could be used in the rail car. It is true that the bearing surface of the head of the ordinary steel rail is not sufficient to take the necessary wheel load when supported by free rubber tires; but it may be possible to use air in a rubber shoe that is enclosed in a steel case, one side of which is the tread and flange of the car wheel.

A new street railway car chassis now is being developed, which will embody wheels that are both pneumatically resilient and individually driven. The bearings are to be of the nonfriction type and installed on the inside of the wheels. The axles are to be split; the brakes a combination of electric shoe and magnetic track and air actuated clasp. One of the difficulties of rail car operation is the low coefficient of friction between the steel rail and the car wheel. The individually driven wheels increase the traction, and should the wheels tend to slip there is more tractive effort than with the conventional 4-motor double-truck street car. The electrical equipment will consist of 8 new 25 horsepower motors with automatic control.

The Trolley Coach

Some operators do not believe that any vehicle that is limited to fixed rail operation is the answer to the urban highway transportation problem because the performance in competition with other vehicles is bound to be inferior. One of the world's transportation authorities, Lord Ashfield, in a paper on London passenger transportation presented before the Royal Institute of Great Britain, stated, "The solution of the transportation problem appears to be in the direction of the trackless trolley vehicle . . . ." Already a number of the trams in London has been replaced by the double deck trolley coach, and this transformation is well under way. During the past few years quite a number of cities in the United States, including Brooklyn, Boston, Columbus, Chicago, Cleveland, Dayton, Indianapolis, Providence, Salt



Elevation of new street railway car now being developed, with pneumatically-resilient individually-driven wheels

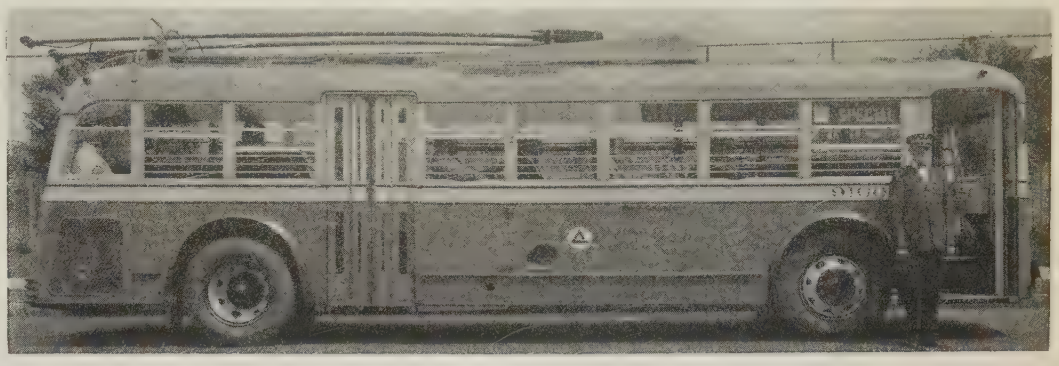
A paper based upon an oral presentation before the transportation group of the A.I.E.E. New York Section, April 30, 1935; recommended for publication by the A.I.E.E. committee on transportation. Manuscript submitted May 22, 1935; released for publication Nov. 15, 1935; revised and brought up to date Feb. 1, 1936.

The author desires to express his sincere appreciation to all the representatives of the manufacturing companies, including the A.C.F. Motors Company, General Electric Company, General Motors Truck Corporation, Mack-International Motor Truck Corporation, Ohio Brass Company, Twin Coach Corporation, Westinghouse Electric and Manufacturing Company, the White Motor Company, and others who have co-operated in such a whole-hearted manner in the developmental work. Particular credit is due to Col. George A. Green, of the General Motors Truck Corporation, L. C. Josephs, Jr., of the Mack-International Motor Truck Corporation, and Guy Wilson, of the General Electric Company.

Lake City, San Francisco, and Shreveport have adopted trolley coach operation. Other parts of the world in which trolley coaches are being installed include Australia, Belgium, China, Germany, Holland, Italy, Japan, Morocco, New Zealand, Poland, South Africa, Straits Settlements, and Switzerland. It is interesting to note that in some of these coaches features are embodied that are not yet adopted in a practical way in America, i. e., a combination of regenerative and rheostatic braking, as well as the exclusive use of the single propulsion motor.

ing depot, and *vice versa;* it may be stored anywhere at the end of the line between peaks; it may operate out of convenient places or garages; and it may attract more special trips or business than any vehicle fixed to a particular route by wires or rails, and thereby the increase in both service and earnings easily may amount to large sums annually. Traffic requirements are ever changing from fixed routes due to new highways, parks, amusement places, business, civic centers, and housing developments. New conditions such as these also are easily met by the motor bus.

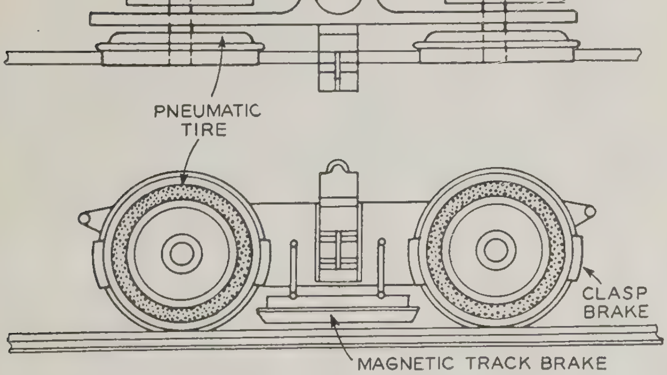
One of the 62 all-service vehicles now in operation on the Public Service system



Although the trolley coach allows curb loading and free running over at least a 60 foot street and has a very favorable acceleration, hill climbing, and comfortable economical performance, it still falls short in some of the advantages held by the gasoline motor bus.

The Gasoline Motor Bus

The motor bus may take advantage of the shortest distance in going to the various lines from the operat-



Truck of new car with pneumatically-resilient individually-driven wheels

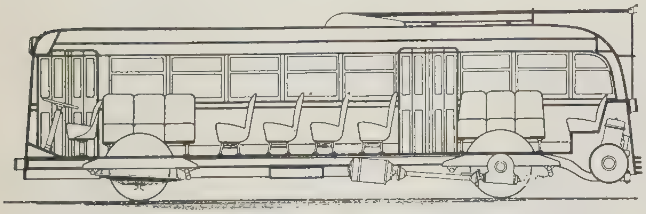
The gasoline motor bus, however, has its shortcomings. The necessity of shifting gears and clutches even if accomplished by power, takes too much of the driver's time and energy in city operation that may well be used in other duties, such as attention to passengers boarding and alighting, speeding up schedules, and the collection of fares. There are city motor bus lines on which during a round trip the driver is required to operate for approximately 50 per cent of the elapsed time in first and second gears. Then too, the large engine produces large quantities of exhaust gases, which are aggravated by making stops and quickly changing engine speeds through the gears. When the driver takes his foot off the accelerator pedal to make a stop, the inertia of the vehicle drives the engine, drawing in gas that is discharged unburned through the exhaust and finally finds its way into the bus by way of the windows and doors. Fortunately, this raw gas is not dangerous, but, unfortunately, it nauseates the passengers; and it is very difficult to convince the average person that the fumes are not deadly carbon monoxide.

The foregoing criticism should not be leveled against the gasoline-mechanical bus in intercity or interstate operation. This vehicle as it is now being developed, including better performance, less weight, additional comfort, and wider appeal, with improved baggage and seating facilities, air conditioning and new heating and lighting fixtures, is a great compliment to the automotive engineer.

The Gasoline-Electric Motor Bus

The gasoline-electric motor bus overcomes most of the objections to the gasoline bus in city operation. It substantially eliminates gas fumes, presuming that the engine and accessories are maintained reasonably

well. This is because the engine speed is more constant than in the gasoline-mechanical bus, there is no physical connection between the prime mover and the driving wheels, and the bus is controlled principally by the accelerator pedal without shifting of gears or clutches. Actual experience with bus operators of both gasoline-mechanical and gasoline-electric busses is that drivers avoid the gear shift busses if there is an opportunity to do so, and there is less turnover of drivers where gasoline-electric busses are used. It also has the distinct advantage in ease to bring the bus back to newness by substituting independent unit parts. When full consideration is given to upkeep, including depreciation, it is



Cross-section of the new all-service vehicle

more economical in city operation than the gasoline motor bus and, except for obsolescence, may be called the ageless vehicle.

The principal criticism against the gasoline-electric bus formerly was lack of power. This was not the fault of the idea, but was attributable to the fact that comparatively light-weight gasoline engines for motor busses were not built until recently with sufficient and reliable power characteristics. Another overworked objection was the additional weight and cost. Fortunately, the latter do not have any significance unless considered in the light of accomplishments. The fact that the commercial "Clipper" seaplane weighs 48,000 pounds does not detract from the feat of flying with full load from California to Hawaii in 18 hours, which was 7 hours less than ever before. It is also interesting to note when international marine engineers desired to design and construct the safest, fastest, and most comfortable ocean liner they included electric drive in the S.S. "Normandie." However, both extra weight and cost may be largely eliminated if need be by using a single electric motor directly connected to the differential and a smaller high speed or supercharged engine which, when connected electrically, will give sufficient torque and power that is more satisfactory than when the same engine is installed in a comparable gasoline-mechanical bus. Here then is an opportunity for further development in the electric drive by the engineer.

It is recognized that both the gasoline-mechanical and gasoline-electric motor busses have the inherent weakness that is characteristic of the gasoline engine; that is, if the engine is large enough to develop sufficient acceleration and hill climbing ability to obtain performance anywhere near that of the private automobile, the engine must be very large, making it heavy and inefficient for average free running speeds.

The Diesel Bus

The Diesel or the compression ignition engine is efficient at most any load factor and has possibilities in low fuel cost. In Europe, where there is a large difference between the cost of gasoline and fuel oil, thousands of busses and trucks with oil engines are being used extensively. Foreign experience shows that some form of an infinitely variable transmission is required for best performance. This problem now is being solved in a way with torque converters, fluid flywheels, and epicyclic gear trains. It is at once apparent that the electric drive, as developed in the United States, would be the ideal solution of the Diesel hook-up. Diesel engines now are appearing in the United States in competition, but there are still serious problems to work out in connection with production, weight, and cost.

The All-Service Vehicle

Now the query is: What may be constructed satisfactorily today to embody into one vehicle the most good points the trolley car, trolley coach, and motor bus? The "all-service" vehicle seems to be one answer. In the initial experiment, an ordinary gasoline-electric bus was equipped with a set of trolley poles and the original electric controller replaced by a double one so that the driver of the

Interior of the all-service vehicle

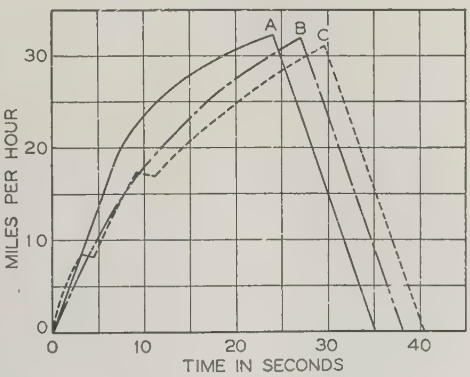
vehicle could shift from one operation to the other at will. The trial was conducted on Pershing Road, extending about 1/2 mile from the West Shore Rail-

road and Ferry Company's terminal to the Hudson County Boulevard East at Weehawken, N. J.

On the day of the test the vehicle ascended the 7 per cent grade at a speed of 30 miles per hour with full load of passengers. This compares with a normal maximum speed on the hill for ordinary gasoline-electric busses of 10 to 13 miles per hour; street cars 12 to 15; interstate gasoline-mechanical busses 15 to 18; and private automobiles 20 to 40 miles per hour. It was determined from electrical data, that if a gasoline-mechanical bus were to duplicate the performance of the "all-service" vehicle, it would require an engine of approximately 250 horsepower.

The results of experiments with the all-service type of vehicle were so satisfactory that 62 busses of this type now have been built and placed in operation on the Public Service system, and an additional 25 are now on order, which will include one with Diesel engine and single propulsion motor. These vehicles resemble the modern front-entrance center-exit "Metropolitan" type of motor bus, with a pair of trolley poles. The metal body is of light-weight streamlined construction. Seats are provided for 36 passengers. Cross seats are used in the center of the vehicle, with longitudinal seats over the wheels which form wells adjacent to the front and center exit doors. The seats themselves are of the airplane type, combining light weight and passenger comfort. Shatterproof glass is used in all windows. The doors are operated pneumatically, and the center door has sensitive edges with an electrical interlock with the control. Mirrors are installed in a manner to enable the operator to obtain a full view of the center exit door even when passengers are standing in the aisle. Heating is carried out by a new design, being a combination hot water and electric unit with an electrically driven blower and thermostatic control. Hot water from the cooling system of the engine furnishes the heat for the vehicle when operated as a motor bus, and an electric resistance when the vehicle is run as a trolley coach. When the vehicle operates at long intervals as a trolley coach, a small pump keeps the engine warm by circulating hot water through the electrical unit. This affords easy starting of the engine in cold weather. Ventilation is accomplished by means of a combination system. Fresh air is taken in at the front of the bus through 2 longitudinal ducts, one on each side, with slotted openings. The air is exhausted through adjustable gratings at the front above the windshield. In order to obtain fresh air when the bus is at a standstill, an electrically-driven exhaust-fan ventilator is provided in the ceiling at the rear.

Performance curves of all-service vehicle with 5 stops per mile, compared with that of an equivalent gasoline-mechanical bus

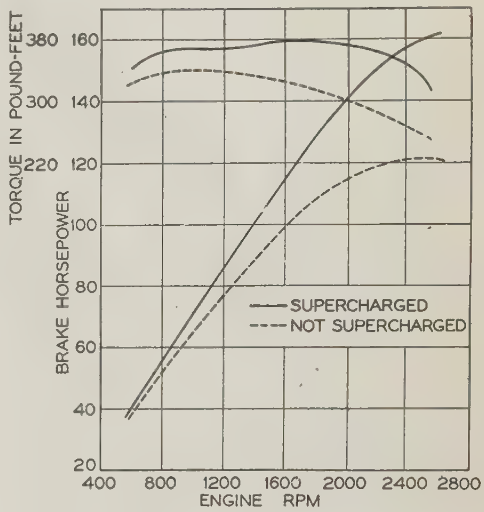


A—Operating as trolley bus on 550 volts; 2 motors; gear ratio 8.75 to 1; tire diameter 42 inches; weight with seated load 24,040 pounds

B—Operating as gasoline-electric bus; 450 cubic inch supercharged engine governed at 2,300 rpm, direct-connected to generator; motors, gear ratio, tire diameter, and weight same as for curve A

C—Curve for equivalent gasoline-mechanical bus; engine same as for curve B; rear axle gear ratio 6.875; low, second, and high speed gear ratios in gear box: 4.7, 2.6, and direct, respectively; weight with passenger load 21,640 pounds

Performance curves of engine in all-service vehicle



Artificial illumination is of the direct type, with special streamlined modernistic fixtures. The new fixtures are so made that the light is directed at an angle toward the floor and rear of the vehicle so that there is no reflection in the windshield and no glare when a passenger enters the vehicle. It is important to note that the auxiliaries are operated from the low voltage battery circuit, instead of having "hot spots" throughout the bus from the overhead trolley. The gasoline engine and its electric generator occupy a transverse position at the rear of the vehicle where they are conveniently accessible for inspection or removal. Placing them there also has the effect of distributing the weight equally on all the tires. The riding quality of the vehicle and the efficiency of acceleration and deceleration are improved by this arrangement; maneuverability also is improved, as a result of the comparatively short wheelbase.

The gasoline engine has a normal rating of 125 horsepower. The engine is equipped with a supercharger, however, increasing its output to approximately 160 horsepower. The use of the supercharged engine is another innovation, as it is the first time surperchargers have been incorporated in bus design.

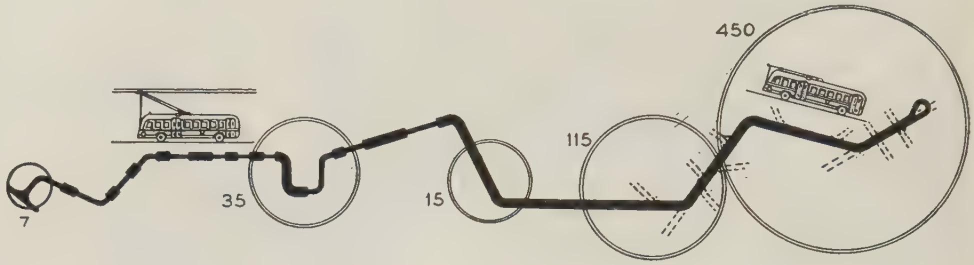
Each of the 2 propulsion motors has a nominal rating of 50 horsepower, giving a total of 100 horsepower for the vehicle. As these motors will take a 200 per cent overload when required for starting,

accelerating, or hill climbing, a maximum of 300 horsepower or more will be available. Because the electric motors can be subjected to this overload, it is expected that the all-service vehicle will be operated on a schedule at least 10 per cent faster than the modern bus equipped with a gasoline engine.

Another important innovation is the provision of 3 independent braking systems that may be used at any time. The first consists of air brakes on 4 wheels; the second of manually operated brakes on the shafts of the 2 propulsion motors, and the third is a dynamic brake operated through the windings of the motors. A new type of selector switch regulates the vehicle when operated either as a trolley coach or gasoline-electric bus. The switch is arranged for neutral, forward, reverse, and electric braking, and there are seven positions in all which will be available for both services.

For safety, it is placed in the "off" position during layovers or when the vehicle is not in use. The control circuits are completed through the selector switch and the foot accelerator switch. With the selector switch in the proper position the initial depression of the foot throttle closes the generator "teaser" field. The generator teaser field is excited from the starting and lighting battery and controlled through the accelerator switch and a voltage relay. The relay is so arranged that the battery field is reduced or eliminated when the generator voltage reaches a predetermined value. This teaser field assures a quick and positive building up of generator voltage under all load conditions. A foot operated switch provides for inserting resistance in the main generator field. Under heavy load conditions the engine thereby may be operated at higher speed, affording more power.

A typical route on which the all-service vehicle is used



Trolley coach operation is controlled by a foot pedal and a foot accelerator is used when the vehicle is run as a gasoline-electric bus. When it is desired to operate the vehicle as a motor bus, the driver, without reducing the speed of the vehicle or leaving his seat, can cause the trolley poles to be pulled down to the roof into automatic locks in 3 seconds by means of electrically operated retrievers. One advantage of the all-service vehicle, which may become an important one, is that it may be operated as a trolley bus through tunnels without the installation of expensive ventilation systems.

Operation and Performance

When the vehicle is operated from 2 overhead trolley wires, with 600 volts difference in potential, the trolley shoes are placed in contact with the wires and the selector switch then is depressed partially until all the series resistance is cut out, securing acceleration of the traction motors. After the foot pedal is fully depressed the motors continue to accelerate the coach according to the motor characteristics curve. The 2 traction motors always are connected in series during operation from the overhead trolley.

To operate the vehicle from the gasoline engine, the trolley poles are lowered, the selector switch is moved to the proper position, and the accelerator pedal is depressed. As the engine generator speed increases, the generator voltage builds up and the driving motors increase in speed. Releasing the accelerator pedal closes the engine throttle. The selector switch need not be moved to the "off" position at regular stops.

The electric brake may be used in case of emergency to reduce the speed of the vehicle, and is very helpful in controlling coach speeds without slipping wheels on severe grades. To do this the selector switch handle simply is shifted to the extreme rear position.

When operating as a trolley coach with passenger load, the free running speed of the vehicle on the level is approximately 40 miles per hour with 600 volts without shunting the motor fields. The maximum safe speed of the motors, with the recommended gear ratio and tire size, is about 63 miles per hour. The vehicle will accelerate on the level from 0 to 25 miles per hour in 13 seconds. As a gasoline-electric bus it is capable of a maximum speed of approximately 50 miles per hour and, will accelerate with passenger load, from 0 to 25 miles per hour in 20 seconds. The engine will deliver a net horsepower of approximately 125 to the generator at 2,200 rpm. Although the specified weight of the vehicle, 18,000 pounds, has been exceeded somewhat, it still has ample power and its performance exceeds that of any commercial trolley coach or gasoline-electric motor bus so far constructed.

Last, but not least, the all-service vehicle in its application is not an instrument that necessitates confiscation or scrapping of existing transportation systems. This is an idea that often has been popular with certain persons having more or less responsibility, and it should, therefore, be refreshing to note that the all-service vehicle by virtue of its characteristics of higher scheduled speeds, flexibility, and economics should be a boon to both the rider and those who provide the service as well.

The Calibration of Microphones

During the past few years, the subcommittee on fundamental sound measurements* of the American Standards Association has been considering definitions and test procedure pertaining to the calibration of microphones. The following report is a result of its work. At a recent meeting of the sectional committee* under which the subcommittee functions, it was voted to submit this work to interested scientific bodies for publication in their journals, with the thought of promoting constructive criticism and discussion.

PERFORMANCE of a microphone, in general, depends on a number of quantities, some of which are not yet amenable to either accurate specification or physical measurement. For noncarbon microphones the more important criteria are: (1) single frequency response; (2) nonlinearity; and (3) directional characteristics. Some of the others are: phase distortion, dependence on atmospheric conditions, stability, noisiness. Carbon microphones, in addition to the foregoing, also exhibit certain characteristics peculiar to granular contacts alone, such as "carbon noise," "breathing," "packing," and others.

The following material is concerned chiefly with noncarbon microphones. The characteristic best admitting of definition and measurement is the single frequency response. This is the ratio of electric output to acoustic input plotted as a function of frequency. For any actual instrument this ratio is not entirely independent of the absolute value of the acoustic input. Therefore, any particular frequency response curve should be regarded as applicable only for inputs within a certain range of magnitudes.

In addition to causing departures from constancy in the output-input ratio, the nonlinearity of an instrument produces extraneous frequencies in the output. For a single frequency input, a simple measure of nonlinearity is the harmonic content of the output.

The quantity "acoustic input" can be specified in more than one way. Most microphones ("pressure microphones") are so constructed that their operation depends primarily on the variations in pressure on the front surface of the diaphragm, the other side of the diaphragm being shielded effectively from the sound waves. There is, however, an important class of microphones in which both sides of the diaphragm are exposed freely, and which are actuated by the pressure gradient in the direction normal to the diaphragm. Since for unobstructed waves pressure gradient is proportional to particle velocity, microphones of the last mentioned class sometimes are referred to as "velocity microphones." Although it might appear logical to specify the response of sensitivity of a velocity microphone in terms of velocity or pressure gradient rather than pressure, it is desirable to use the same acoustic units for all microphones in order that performances may be comparable. The unit chosen is that of pressure, and use is made of the practically constant ratio of sound pressure to air particle velocity for plane progressive waves.

For a microphone used in such applications as broadcasting, recording, and public address systems, the quantity of chief practical interest is the ratio of the microphone output to the sound pressure at the microphone position as it would be if the microphone were not there. This pressure is chosen as a measure of the "acoustic input" in what is known as the "field calibration" of a microphone. The distortion of the sound field caused by the microphone itself thus is charged to the response characteristic of the instrument. The "field response" definition given in a succeeding paragraph refers to a microphone placed in a plane progressive wave, as a specification which is simplest and freest from ambiguity. Microphone response under other conditions may be of interest, such as for close talking, and where such specific calibrations are made the conditions of measurement should be stated.

From the standpoint of microphone design, and in connection with some sound measuring and testing apparatus, an important quantity is the ratio of microphone output to the pressure actually driving the diaphragm. This pressure is taken as a measure of the acoustic input in the "pressure calibration" of a microphone.

The measurement of "electric output" is inherently simpler than that of "acoustic input" since only lumped impedances are involved in the former. In order to separate the performance of the microphone from that of the associated amplifier or other circuit, the use of the open-circuit electromotive force is to be preferred. But in order to obtain a practically significant measure of the output as it affects the associated circuit actually used with the microphone, it is essential to know the internal impedance of the instrument.

Since the direction of the incident sound affects various microphones differently, it is necessary in any field calibration to specify the orientation of the microphone with respect to the source.

A report prepared by the A.S.A. subcommittee on fundamental sound measurements,* and recommended for publication by the A.I.E.E. committee on communication. Manuscript submitted Dec. 9, 1935; released for publication Dec. 17, 1935.

The subcommittee* made use of considerable material from the tentative report of the standards committee on electroacoustic devices of the Institute of Radio Engineers, and this gratefully is acknowledged.

* Subcommittee on fundamental sound measurements of sectional committee on acoustical measurements and terminology (Z24) of the American Standards Association: C. R. Hanna (A'24) *chairman;* Stuart Ballantine, V. L. Chrisler, B. R. Hubbard, A. H. Inglis (A'22), E. W. Kellog, H. W. Lamson (A'18, M'28), H. B. Marvin (A'20), J. P. Maxfield (M'23, F'27), L. J. Sivian, and Irving Wolff.

Field Response. The response of a microphone at a given frequency is given by the ratio E/p, where E is the open circuit voltage generated by the microphone and p is the sound pressure in bars (dynes per square centimeter) at the specified frequency, as measured in a progressive plane sound wave prior to the introduction of the microphone, the microphone being placed at a specified angle with respect to the wave front. The value of E/p has no practical significance unless accompanied by a statement of the internal impedance of the instrument.

Pressure Response. This is the same as field response except that p is the uniform sound pressure in bars on the microphone diaphragm at the specified frequency.

Both the field and pressure responses may be expressed by the value of E/p or may be expressed in decibels relative to the arbitrary reference condition of one volt per bar. Thus, the response in decibels is

$$20 \log_{10} E/p$$

Nonlinearity. The simplest measure of this quantity, although it is not one on which general agreement has been reached, is the following:

$$\frac{\sqrt{E_2^2 + E_3^2 \ldots + E_n^2}}{E_1}$$

In this fraction E_1 is the fundamental frequency electromotive force and $E_2, E_3 \ldots E_n$ are the corresponding electromotive forces of the several harmonics generated. The utility of this measure is largely in the statement of limits which it makes possible. Thus, for a given microphone, it might be possible to state that for all values of fundamental frequency output less than E_1 the harmonic content ratio does not exceed a certain percentage. This ratio, in general, is a function of the fundamental frequency. Furthermore, a knowledge of the harmonic content for all fundamental frequencies is not always sufficient to determine the amount of extraneous frequencies generated when the acoustic input includes 2 or more frequencies.

Directional Characteristics. Usually the field response defined hereinbefore refers to that microphone orientation in which the diaphragm is parallel to the wave front and faces the source. For any other angle of incidence, the field response in general will be different. In addition to the foregoing for "normal" incidence, a useful index is that for "random" incidence. This may be defined as follows:

$$\frac{\text{Efficiency (random)}}{\text{Efficiency (normal)}} = \frac{1}{4\pi} \int_0^{4\pi} f^2(\Omega) \cdot d\Omega$$

The quantity $f(\Omega)$ is the ratio of the voltage output for incidence at the angle Ω to that for normal incidence; expressed in decibels:

$$\frac{\text{E. R.}}{\text{E. N.}} = 10 \log_{10} \frac{1}{4} \int_0^{4\pi} f^2(\Omega) \cdot d\Omega$$

Electromotive Force Generated by a Microphone

The value of the electromotive force generated by a microphone may be obtained as follows: Under the influence of sound of a certain frequency a certain electrical output is obtained from the microphone, either directly or through an amplifier; if now the sound be switched off and a voltage of the same frequency applied in series with the microphone and adjusted to give the same output, the magnitude of this voltage is the open circuit electromotive force produced by the sound. The impedance employed to introduce the voltage in series with the microphone must be so small that its presence, as a passive impedance does not materially alter the microphone output.

Applied Pressure Produced by Sound

The applied pressure may be quoted in terms of either the pressure in the progressive plane wave (field response) or the uniform pressure effective on the diaphragm (pressure response). Several factors can operate to cause difference between the actual effective pressure on the diaphragm and the corresponding undisturbed field, for example:

1. When a microphone is exposed to sound waves of low frequencies (wave length large compared with the size of microphone) the pressure on the microphone is substantially equal to the undisturbed field pressure. At high frequencies, however, diffraction takes place at the face of the microphone. The ratio of the pressure at the diaphragm to that in the free wave becomes a function of the wave length and of the angle of incidence.[1–3]

2. When there is concavity at the face of the microphone, the diaphragm being recessed or fitted with a mouthpiece, the pressure on the diaphragm at certain frequencies may be increased still further since in effect an acoustical resonator is formed.[4–8]

When a microphone is used in a room for transmitting or recording sound, the exact conditions of use are indeterminate since the room itself forms a link in the transmission chain. Assuming that the microphone is facing the source of sound, the sound at the microphone may be divided into 2 components, namely, the initial progressive wave, and the sound produced by reflections. The field calibration is accurately applicable only to the former for which direction of propagation is known. The applicability of the free wave calibration under these circumstances depends therefore on the relative magnitudes of the initial progressive wave and the resultant of the reflected waves; the accuracy decreases as the microphone is moved farther from the source or as the reverberation of the room is increased.

When a microphone is used as a telephone transmitter, the speaking distance being very small, the exact conditions of use are also difficult to specify. (The velocity component of the sound wave is larger in proportion to the pressure component close to a small source of sound than at a greater distance, and a greater conversion of kinetic to potential energy is to be expected.) There appears to be no information available at present as to the inaccuracy involved in the use of the free wave calibration for the close speaking condition.

The most important criteria of the performance of a microphone are the response in relation to frequency and the response in relation to the amplitude of the applied pressure. For a carbon microphone there

1. For all numbered references see list at end of paper.

are other important criteria, for example, the response in relation to the noise generated by the microphone, and response variations likely to result from packing.

Objective Measurements: Direct Calibrations

There are 3 methods in common use at this time to obtain primary calibrations. These may be designated broadly as (1) the thermophone, (2) the electrostatic actuator, and (3) the Rayleigh disk methods. In general, these do not yield the same calibration and not all of these methods are universally applicable to all types of microphones. Methods 1 and 2 apply to pressure calibration, and for field calibration method 3 alone is applicable although this method applies to pressure measurements as well. Only method 3 is applied to microphones of the ribbon type.

The Thermophone

The thermophone as developed by E. C. Wente[9–11] for microphone calibration usually consists of one or more strips of very thin gold leaf mounted on a plate. This plate fits closely over the front of the microphone in such a manner that the air chamber in front of the diaphragm is small. This enclosure generally is filled with pure dry hydrogen at a steady pressure which is approximately atmospheric. The use of hydrogen permits a more nearly uniform distribution of pressure over the diaphragm, even at high frequencies, than would air.

In the usual method, the thermophone strip carries a known steady current upon which a sinusoidal alternating current is superimposed. The alternating pressure in the chamber occurs primarily at the frequency of the alternating current if the a-c component is small compared with the d-c component. The absolute measurement of the a-c component may be eliminated by the use of an attenuator circuit which also serves to calibrate the amplifier voltmeter associated with the microphone by introducing a calibrating voltage in series with the microphone.[12]

To prevent the accumulation of any air leaking back into the enclosure a continuous circulation of hydrogen is maintained; and by the use of equal pressure and exhaust heads, the steady pressure in the enclosure is kept equal to atmospheric pressure, a necessary precaution when calibrating condenser transmitters. Capillary tubes are used for the supply and exhaust ducts to reduce leakage of sound by these paths.

The thermophone method is not restricted to the calibration of condenser microphones. It may be used with a diaphragm of any shape that is not too large relative to the shortest sound wave length (in hydrogen) to be employed. It is required that the acoustic impedance of the microphone be known except when this impedance is large compared with that of the enclosure, in which event the computations are simplified considerably.

Wente's paper[9] gives the pressure generated by a thermophone in an enclosure with rigid walls which are heat insulators on the assumption that the alternating component of the temperature of the thermophone is uniform. It also gives a correction factor for the conduction of heat by the clamps supporting the thermal strips. Wente's solution includes the effect of heat radiation from the thermophone strips. Additional correction factors are required to allow for: (*a*) heat conduction by the walls of the enclosure, (*b*) mechanical yielding of the microphone diaphragm, and (*c*) leakage of sound through the capillary ducts. Factors (*a*) and (*b*) are discussed in papers by Sivian[3] and Ballantine.[13] The latter reference also gives a correction for the capillary ducts. Ballantine's paper discusses in detail many of the features of the thermophone method and gives numerical data including a list of some of the most authoritative values of the physical constants required in the computations.

The Electrostatic Actuator

The following self-actuator methods are primarily applicable to condenser microphones in which a substantially uniform electric force can be applied by means of a plane electrode parallel to the diaphragm.

Sound Pressure Compensated by Electric Force Applied to Diaphragm. In this case the microphone is made to act as its own electrostatic actuator. The original publication of this method was given by Gerlach.[14] An electroacoustic device is required whose diaphragm motion can be detected by acoustic or electroacoustic means, and which at the same time can have applied to its diaphragm an electrically produced force that is capable of calculation or measurement. The distribution of the electrical force over the diaphragm must be substantially like that of the acoustic pressure caused by the applied sound.

The device is subjected to a sustained sound which causes the diaphragm to vibrate. If now the alternating force be applied at the same frequency and adjusted correctly in phase and magnitude, the diaphragm can be brought to rest. It is then only necessary to ascertain the magnitude of the electrically applied force in order to evaluate the magnitude of the force resulting from sound. A variation of this method is described by Hartmann.[15] The balance between acoustic and electric forces is judged by absence of variation in the microphone capacitance. This is done by making the microphone a part of the high frequency modulation circuit similar to the one described in connection with the following method.

Microphone Capacitance Variation Measured in a Frequency Modulated Circuit. The calibration is made in the absence of sound by observing the microphone output produced by vibration of the diaphragm when it is actuated by the electric force. The method is described by Grutzmacher and Meyer.[16]

In this method the condenser microphone is used simultaneously in 2 circuits: (1) its normal polarizing circuit, and (2) the capacitance between the electrodes of the microphone is made part of a high frequency oscillation circuit. There is inserted in the polarizing circuit an alternating voltage which causes the diaphragm to vibrate at audio frequencies. The resultant capacitance variation of the microphone

is used to produce frequency modulation (which is measured by suitable means) of the high frequency circuit. It remains to determine the factor of proportionality between the voltage applied in the polarizing circuit and the force it exerts on the diaphragm. This is done by observing the voltage required to produce a capacitance change equal and opposite to that produced by a known static air pressure.

Auxiliary Electrode Method. This method is described by Sivian,[3] Grutzmacher and Just,[17] and Ballantine.[13] The electric force is applied by means of an auxiliary electrode in front of the diaphragm, thus eliminating the necessity of using the frequency modulated circuit. This also permits a practically uniform distribution of electric force over the diaphragm area, which is not possible with the usual shape of the back electrode of the microphone in the self-actuator. The magnitude of the electric force readily is computed from the known separation between the diaphragm and auxiliary electrode. The latter is perforated in such manner that it does not alter appreciably the impedance opposing the motion of the diaphragm when the latter vibrates in free air.

An alternative procedure is to obtain the relative frequency characteristics by means of the auxiliary electrode method and then to make an absolute calibration at a single convenient low frequency by the "piston phone" method.[9]

Rayleigh Disk

In order to use a Rayleigh disk for calibrating a microphone it is necessary to expose both instruments in a sound field of such simple character that the relation between velocity and pressure is known.[2]

Stationary-Wave Pressure Calibration. The diaphragm of the microphone closes one end of the tube in which a plane stationary wave is maintained by a suitable source. A Rayleigh disk, suspended into the tube at a distance that is an odd number of quarter wave lengths from the diaphragm measures the velocity V. The magnitude of the pressure on the diaphragm is then $\rho c V$, regardless of the diaphragm impedance. When the diaphragm impedance per unit area is large compared with ρc, as it is for condenser microphones, the point at which V is measured is also a point of maximum velocity in the stationary wave; ρ is the density of air and c is the velocity of sound in air.

Field Calibration by Rayleigh Disk.[20, 21] Practically, it is convenient to work with a progressive spherical sound wave in which the ratio between the pressure and velocity is known. The chief difficulty in applying this method is that of obtaining the spherical wave. Two requirements must be satisfied: Reflection of sound other than that caused by the microphone under test must be practically eliminated, and (in the absence of a spherical source) the source of sound must be small compared with the wave length. The first condition is met over a restricted frequency range by the use of a testing cabinet with heavily absorbing walls.

Some error may result from sound reflected from the microphone if this is not small. The accuracy of measurement can be improved by taking a mean of results from different locations of the microphone in the cabinet. Alternatively, a larger cabinet would permit greater distance between the microphone and the source and disk.

This is a field calibration. That the free wave calibration can be made by a Rayleigh disk is attributable to the fact that the disk itself offers no appreciable obstruction to the sound wave, that is, it is effectively small at all frequencies used. The use of a spherical wave is not essential; but in view of the difficulty of obtaining a plane wave in free air, spherical radiation provides the simplest progressive wave that can be obtained readily in practice.

Rayleigh Disk Used as Torsional Pendulum. This method is described by Sivian.[22] Its principal purpose is to increase the signal-noise ratio; that is, to increase the ratio of the disk deflection caused by the sound measured to its erratic deflections caused by spurious air currents. The desired discrimination is effected by reading the amplitude of oscillation of the disk vibrating as a torsional pendulum at its resonant frequency. The oscillatory torque is produced by using a sound field the amplitude of which is modulated with a frequency equal to that of the disk, which may be of the order of 0.4 cycle per second. The modulated sound field is obtained by: (*a*) feeding the sound source through a motor driven potentiometer that varies the current sinusoidally at the required rate (for example, 0.4 cycle per second), or (*b*) feeding the sound source from 2 oscillators the frequencies of which differ by the natural frequency of the disk (for example, 0.4 cycle per second).

Objective Measurements: Indirect Calibrations

A high quality microphone, having been calibrated, may be used as a standard of comparison for calibrating other microphones. The acoustical conditions required for the test are essentially the same as those for measuring the free wave pressure at a point produced by radiation from a loud speaker; this measurement may comprise the preliminary step toward the indirect calibration of a microphone, the final steps being taken by replacing the calibrated microphone by the one under test and repeating the measurement. If the sizes or shapes of the 2 microphones be dissimilar, it is desirable that the test be made with the microphone at such distance from the source of sound that sound reflected from the former should not affect appreciably the radiation efficiency of the latter. Measurements of this kind have been described, for example, in the publications of Cohen, Aldridge, and West,[21] and by Grutzmacher and Just.[17]

References

1. Effect of Diffraction Around the Microphone in Sound Measurements, Stuart Ballantine. *Phys. Rev.*, v. 32, Dec. 1928, p. 988.

2. Measurement of the Sound Pressure on an Obstacle, W. West. I.E.E. (London) *Jl.*, v. 67, Sept. 1929, p. 1137.

3. Absolute Calibration of Condenser Transmitters, L. J. Sivian. *Bell Sytem Tech. Jl.*, v. 10, Jan. 1931, p. 96.

4. Effect of Cavity Resonance on the Frequency Response Character

[4.] ...ISTICS OF THE CONDENSER MICROPHONE, Stuart Ballantine. I.R.E. *Proc.*, v. 18, July 1930, p. 1206.

5. THE PRESSURES OF THE DIAPHRAGM OF A CONDENSER TRANSMITTER IN A SIMPLE SOUND FIELD, W. West. I.E.E. (London) *Jl.*, v. 68, Apr. 1930, p. 441.

6. CALIBRATION OF WENTE CONDENSER TRANSMITTER, A. J. Aldridge. *Post Office Elec. Engrs. Jl.* (London), v. 21, Oct. 1928, p. 223.

7. IMPROVED CONDENSER MICROPHONE FOR SOUND PRESSURE MEASUREMENTS, D. A. Oliver. *Jl. Sci. Insts.*, v. 7, Apr. 1930, p. 113.

8. FREQUENCY CHARACTERISTICS OF STANDARD REFERENCE-TYPE CONDENSER TRANSMITTERS AND MOVING-COIL RECEIVERS, W. West. *Post Office Elec. Engrs. Jl.* (London), v. 24, Apr. 1931, p. 27.

9. THE THERMOPHONE, E. C. Wente. *Phys. Rev.*, v. 19, Apr. 1922, p. 333.

10. THE THERMOPHONE AS A PRECISION INSTRUMENT, H. D. Arnold and I. B. Crandall. *Phys. Rev.*, v. 10, July 1917, p. 22.

11. SPEECH AND HEARING, Harvey Fletcher. Appendix A. D. Van Nostrand, Inc.

12. REFERENCE CIRCUIT FOR TELEPHONE TRANSMISSION MEASUREMENTS, L. J. Sivian. *Elec. Communication*, v. 3, Oct. 1924, p. 114.

13. TECHNIQUE OF MICROPHONE CALIBRATION, Stuart Ballantine. Acous. Soc. of Am. *Jl.*, v. 3, Jan. 1932, p. 319.

14. MESSUNG VON SCHALL-DRUCKAMPLITUDEN, Erwin Gerlach. *Wiss. Veroff. Siemens-Konzern*, v. 3, 1923, p. 139.

15. SCHALLDRUCKMESSUNGEN AN MIKROPHONEN, TELEPHONEN UND IM FREIEN SCHALLFELD, C. A. Hartmann. *Zeit. fur tech. Phys.*, v. 10, Nov. 1929, p. 553.

16. EINE SCHALLREGISTRIERVORRICHTUNG ZUR AUFNAHME DER FREQUENZKURVEN VON TELEPHONEN UND LAUTSPRECHERN, Martin Grutzmacher and E. Meyer. *Elek. Nach. Tech.*, v. 4, May 1927, p. 203.

17. ÜBER KOHLEMIKROPHONE, Martin Grutzmacher and P. Just. *Elec. Nach. Tech.*, v. 8, March 1931, p. 104.

18. HYDRODYNAMISCH-AKUSTISCHE UNTERSUCHUNGEN, Walter Koenig. *Annalen der Physik und Chemie*, v. 43, Apr. 1891, p. 43–60.

19. THE CALIBRATION AND PERFORMANCE OF THE RAYLEIGH DISK, E. J. Barnes and W. West. I.E.E. (London) *Jl*, v. 65, Sept. 1927, p. 871.

20. SOME ACOUSTIC EXPERIMENTS WITH TELEPHONE RECEIVERS, E. Mallett and G. F. Dutton. I.E.E. (London) *Jl.*, v. 63, May 1925, p. 502.

21. THE FREQUENCY CHARACTERISTICS OF TELEPHONE SYSTEMS AND AUDIO-FREQUENCY APPARATUS AND THEIR MEASUREMENT, B. S. Cohen, A. J. Aldridge and W. West. I.E.E. (London) *Jl.*, v. 64, Oct. 1926, p. 1023.

22. A MODIFICATION OF THE RAYLEIGH DISK METHOD FOR MEASURING SOUND INTENSITIES, L. J. Sivian. *Phil. Mag.*, v. 5, March 1928, p. 615.

Sinusoidal Traveling Waves

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The theory of transients arising from the sudden application of a sinusoidal potential is presented in this paper, for the distortionless transmission line. The solution is given in the form of a series of damped sinusoidal traveling waves, the reflections diminishing progressively until the steady state is reached. Oscillographic tests on an artificial line containing lumped parameters are shown to corroborate the theory, and graphical methods are described which permit a quick computation of the successive traveling waves.

CONSIDERABLE investigation has been made analytically and experimentally of transients on transmission lines caused by suddenly impressed d-c potentials and lightning surges. In the mathematical approach, Heaviside's operational method[1,2] proves a powerful tool and leads to the theory of traveling waves of electric energy. Several graphical methods,[3,4] based upon it, have been developed for computing the surges and transients caused by applying a d-c potential to a line.

Although several mathematical solutions[5,6,7] have been obtained for the transients caused by a-c potentials, the results usually are expressed in formidable equations which do not permit ready graphical treatment. In some solutions[6] the emphasis has been placed upon the building-up process of sinusoidal signal currents in the line. Since the operational form of the general mathematical solution for the transient state does not require the specification of the nature of the applied potential, the theory for alternating applied potentials should embrace the case of continuous potentials. It is, therefore, the object of the present investigation to obtain a solution for the transient condition on a transmission line which: (1) is correct regardless of the nature of the applied potential, whether alternating, continuous, or any other form; (2) gives the steady state solution as the asymptotic state of the transient period; and (3) permits a simple graphical treatment.

Because considerable simplification and good practical approximation are obtained by treating the line as distortionless, it will be assumed that the line parameters per unit of length are so related that the resistance, R, divided by the inductance, L, is equal to the leakance, G, divided by the capacitance, C. Some distortion of the waves will occur, however, on real lines.

SEMI-INFINITE LINES

If a sinusoidal potential be impressed suddenly on a de-energized single-phase transmission line extend-

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A condensed version of a thesis "Transients on Transmission Lines Due to Applied Sinusoidal Potentials" by Frank E. Kulman, Polytechnic Institute of Brooklyn, N. Y., June 1935. Acknowledgment is made to F. E. Canavaciol and H. B. Hanstein who respectively provided the artificial line and assisted in the oscillographic measurements.

1. For all numbered references see list at end of paper.

ing from the point of application to infinity, a wave of electromagnetic energy will be propagated along the line with a velocity, $v = 1/\sqrt{LC}$. In overhead lines the velocity of propagation approaches the velocity of light. In conformity with the principle of equipartition of energy, half the energy is in the electrostatic field and half in the electromagnetic field so that (see appendix)

$$Ce^2 = Li^2 \tag{9}$$

This relation defines the ratio of components of potential and current in the wave so that

$$\frac{e}{i} = \sqrt{\frac{L}{C}} = R_s \tag{8}$$

where R_s is the surge impedance, or more appropriately the surge resistance, of the line.

Potential and current are propagated with constant phase relation with respect to each other. The equations of potential and current propagated are

$$e = \epsilon^{-\frac{x}{v}(\delta+p)} E(t)1 = \epsilon^{-\frac{x}{v}(\delta+j\omega)} E_m\epsilon^{j(\omega t+\psi)} \tag{22}$$

$$i = \epsilon^{-\frac{x}{v}(\delta+p)} \frac{1}{R_s} E(t)1 = \epsilon^{-\frac{x}{v}(\delta+j\omega)} \frac{E_m}{R_s} \epsilon^{j(\omega t+\psi)} \tag{23}$$

where

$E(t) = E_m\epsilon^{j(\omega t+\psi)}$, applied potential
x = distance from sending end
δ = attenuation constant = R/L
p = Heaviside operator which in the exponential function shown indicates propagation with velocity v.

Because of the inherent resistance and leakance in the line, the wave is a damped sinusoidal space function, the character of the attenuation being an exponential function of the distance from the sending end. The vertical front of the wave has a relative magnitude depending on the switching angle ψ of the applied potential, being greatest when the alternating potential is applied at positive or negative maximum value. When the wave passes a given point at a distance x_1 on the line, the potential and current at that point increase abruptly from zero to the value of the wave front and then oscillate with the impressed frequency, the amplitude of the oscillations being respectively

$$E_{mx_1} = E_m\epsilon^{-\frac{x_1}{v}\delta} \tag{24}$$

$$I_{mx_1} = \frac{E_m}{R_s}\epsilon^{-\frac{x_1}{v}\delta} \tag{25}$$

The potential or current at any point, therefore, can be represented by a time vector that comes into existence when the wave reaches that point, the angular velocity of rotation in the time diagram being identical with that of the applied potential.

The phase difference between one point on the line and another point at a distance Δx therefrom is $\Delta\phi = (\omega/v)\Delta x$, the phase leading at the point closer to the sending end. The angle ω/v is called the wave length constant and represents the phase shift per unit length. For a phase difference of 2π radians the distance between the 2 points is equal to one wave length, approximately 3,100 miles for a 60 cycle per second overhead line.

Finite Lines

For a semi-infinite line, the direct wave continues outward with no reflections, and the potential and current are given by the equations referred to hereinbefore. Similarly, no reflections will occur in a finite line terminated in a resistor the ohmic value of which is identical with the surge resistance of the line; in this special case, the energy flows continuously along the line into the resistor where it is converted into heat. For any other termination of a finite line, part of the direct wave is reflected and the remainder is absorbed in the terminal impedance. The proportion of the reflected wave to the direct wave is given by the reflection factor

$$K = \frac{R_s - Z_0(p)}{R_s + Z_0(p)} \tag{14}$$

where $Z_0(p)$ is the value of the terminal impedance.

If K be constant, the shape of the wave will suffer no distortion in reflection. The extreme values of K occur in a short-circuited and an open-circuited line, where K is $+1$ and -1, respectively. The entire wave is reflected under these conditions, the negative sign indicating a change of polarity in reflection.

The mathematical treatment (see appendix) gives the transient as an infinite series, each term of which represents a wave. The series for the potential transient is

$$e(x,t) = \Big[\epsilon^{-\frac{x}{v}(\delta+p)} - K\epsilon^{-\frac{2l-x}{v}(\delta+p)} + K\epsilon^{-\frac{2l+x}{v}(\delta+p)} - K^2\epsilon^{-\frac{4l-x}{v}(\delta+p)} + K^2\epsilon^{-\frac{4l+x}{v}(\delta+p)} \ldots\Big]E(t)1 \tag{17}$$

The series for the current transient is similar except that $E(t)$ is multiplied by $1/R_s$ and the signs of all the reflection terms are positive. The change in sign between current and potential reflections indicates that the polarity of the current reflection is opposite to that of the potential reflection, so that at any point on the line a phase difference between current and potential is established progressively.

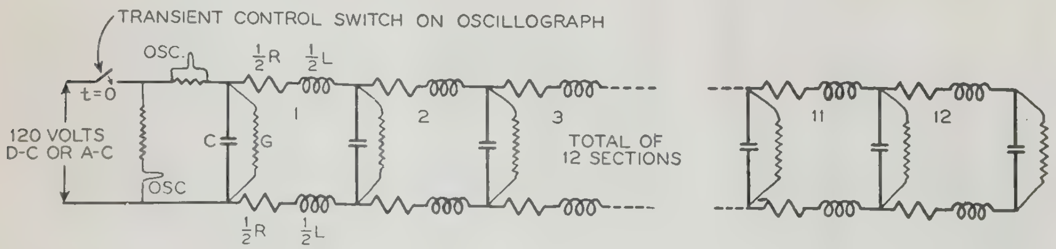


Fig. 1. Schematic diagram of artificial line

See table I for circuit constants

After a theoretically infinite number of reflections, the steady state currents, potentials, and phase angles are reached. Practically, the transient period is completed in a few seconds or fractions of a second.

Solution for the steady state potential is the summation to infinity of all the reflections as follows:

$$e(x) = \left[\epsilon^{-\frac{x}{v}(\delta+j\omega)} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml+x}{v}(\delta+j\omega)} - \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml-x}{v}(\delta+j\omega)}\right] E_m \epsilon^{j(\omega t+\psi)} \quad (27)$$

$$e(x) = \left[\cosh(\sqrt{RG} + j\omega\sqrt{LC})x - (1 + 2\sum_{m=1}^{m=\infty} K^m \epsilon^{-(\sqrt{RG}+j\omega\sqrt{LC})2ml} \sinh(\sqrt{RG} + j\omega\sqrt{LC})x\right] E_m \epsilon^{j(\omega t+\psi)} \quad (28)$$

the latter being corroborated by the solution based upon the well-known complex steady-state theory

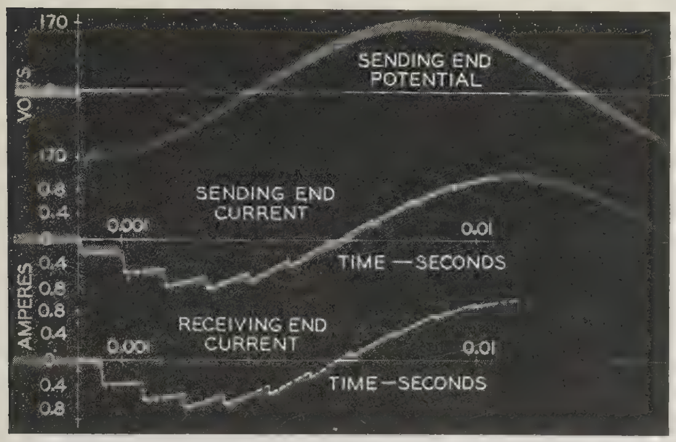


Fig. 2. Transient currents on short-circuited line with alternating potential applied; switching angle 270 degrees

Dotted curves show calculated transients

of transmission lines. The solution for the steady state current is

$$i(x) = \left[\epsilon^{-\frac{x}{v}(\delta+jw)} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml+x}{v}(\delta+j\omega)} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml-x}{v}(\delta+j\omega)}\right] \frac{1}{R_S} E_m \epsilon^{j(\omega t+\psi)} \quad (30)$$

$$i(x) = \left[(1 + 2\sum_{m=1}^{m=\infty} K^m \epsilon^{-(\sqrt{RG}+j\omega\sqrt{LC})2ml}) \cosh(\sqrt{RG} + j\omega\sqrt{LC})x - \sinh(\sqrt{RG} + j\omega\sqrt{LC})x\right] \frac{1}{R_s} E_m \epsilon^{j(\omega t+\psi)} \quad (31)$$

Oscillographic Measurements

With a view to illustrating the theory, measurements were made of the currents at the sending and receiving ends of a distortionless artificial power line with 60 cycle alternating potential suddenly impressed. The measurements were made with the far end of the line short-circuited and open-circuited. The artificial line consisted of 12 Π sections, the parameters of each section being given in table I. A schematic diagram of the line is shown in figure 1. The line is equivalent to 97 miles of single phase overhead line.

Table I—Data and Measurements on Artificial Transmission Line

Number of sections	12	
Structure of section	Π	
Parameters per Section		
Resistance (R)	8.28	ohms
Inductance (L)	0.0292	henry
Capacitance (C)	0.064×10^{-6}	farad
Leakance (G)	18.1×10^{-6}	mho
Equivalent Overhead Line		
Length	97.	miles
Resistance	1.03	ohms per mile
Inductance	0.0036	henry per mile
Capacitance	0.0079×10^{-6}	farad per mile
Leakance	2.2×10^{-6}	mho per mile
Distortion coefficient	0.0	
Attenuation coefficient	0.865	
Surge impedance	650.	ohms

The results of measurements made with 120-volt 60-cycle potential impressed on the short-circuited line are shown in figures 2 and 3, for maximum and minimum values of switching potential. The transients, calculated by the traveling wave theory, are plotted in dotted lines for comparison.

It may be seen from figure 2 that the potential is applied at the instant of maximum negative value. Therefore, a negative current wave is propagated, equal in magnitude to the potential divided by the surge resistance of the line, or 0.26 ampere. The surge reaches the receiving end after 0.0005 second, having been attenuated to 0.865 of its initial value, or 0.22 ampere. Since the line is short-circuited, the reflection has the same sign and magnitude as the direct wave, so that the oscillogram shows a current at the receiving end of 0.44 ampere. After another 0.0005 second interval, the reflected wave reaches the sending end, attenuated. It is reflected here again without change of sign, so that it adds on the direct wave. The reflections travel back and forth, being superposed and attenuated continuously until the steady-state short-circuit current of 0.73 ampere (effective) is reached. The duration of the transient state is 0.02 second.

Figure 3 shows the transient currents when the switching angle is zero. Since the switching potential is initially zero, the wave front is a damped sinusoid with a zero value at the leading point. Since there is no abrupt wave front, the effect of the reflections is not to change the magnitude of the current abruptly as the wave passes a given point in the line, but rather to change the phase angle of the current. The changes of phase angle occur at the time intervals indicated on the oscillograms of sending end and receiving end currents on figure 3. The changes of phase angle are largest for the first few reflections and diminish progressively until the steady state current of 0.73 ampere is reached in approximately 0.02

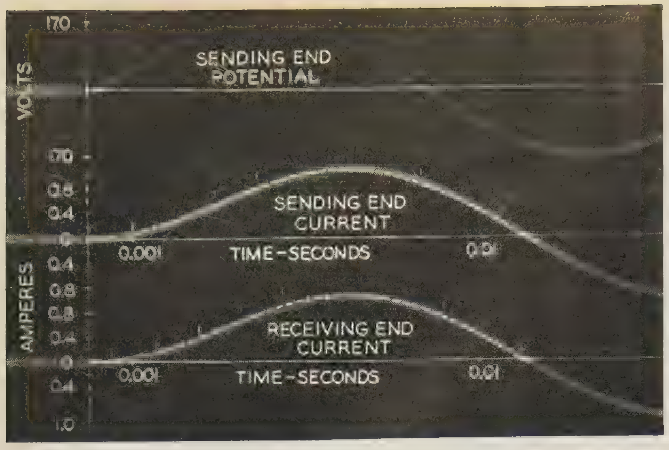


Fig. 3. Transient currents on short-circuited line with alternating potential applied; switching angle 0 degrees

Dotted curves show calculated transients

second. The steady state currents in figure 3 are the same as in figure 2 where the switching potential was at maximum.

Figure 4 shows the oscillograms obtained when a 120-volt 60-cycle potential was impressed on the open-circuited line. The switching angle is 112.5 degrees, or 22.5 degrees after the positive maximum. For the first interval of time, the current at the sending end is given by the potential divided by the surge resistance, or 0.22 ampere. The initial wave reaches the open end attenuated and is reflected with a change of sign so that the reflection is negative. When the reflection reaches the sending end, the current at this end becomes negative because of a reflection at this point. Succeeding reflections occur as shown on the oscillograms, until the steady state current of 0.048 ampere (effective) is reached. This is the charging and leakage current of the line. The duration of the transient state is again approximately 0.02 second.

It may be noted from the figures that the oscillograms substantially corroborate the transient currents as computed by the theory. Small deviations of the measured transient from the theoretical occur for the following reasons:

1. The artificial line, having lumped parameters, does not have a true velocity of propagation and the wave fronts are not perpendicular. However, the virtual propagation of the artificial line checks the true propagation of the transmission line.

2. The lumped parameters cause local high frequency oscillations in the line sections. The frequency of oscillation is 3,700 cycles per second.

3. The effect of inertia of the galvanometer is to cause the light beam to overshoot and oscillate about the true deflection. However, the oscillation of the light beam is damped rapidly and dies out in one cycle as shown in the oscillograms of potential.

Graphical Methods of Computation

Each of the terms in the summation of the power series solution is a traveling sinusoid, damped exponentially along the line. At any fixed point on the line, each term is a vector rotating at the frequency of the applied electromotive force and having a definite phase angle with respect to the applied potential. The addition, therefore, consists of adding the terms in a converging series of vectors, so that the steady state vector finally is obtained, equal to the sum of the series.

Figure 5 shows the computation of the transient current at the sending end of a short-circuited line when a 120-volt 60-cycle potential suddenly is impressed. The parameters and data of the line are given in table I. The switching angle is 270 degrees, so that maximum negative potential is impressed. In this figure the vector diagrams are given at the left, and the graphs of the applied potential and transient current at the right. The vectors of both diagrams are plotted with reference to the position of the vector of applied potential at $t = 0$. The vectors in the current diagram represent not the individual reflections but the sum of all the reflections that have occurred up to the time when the vector comes into existence. For the first interval of time equal to $2\ l/v$, the current at the sending end is equal to the applied potential divided by the surge resistance and is represented by vector 01, equal to E_m/R_s, in figure 5*b*. The current for the interval is in phase with the potential. The reflection of the direct wave of current at the receiving end is without change of sign, so that the reflected wave is superposed on the direct wave and the sending end current is increased in the negative direction. When the reflected wave reaches the sending end, it is doubled in value. The current for the interval of time between $2l/v$ and $4l/v$ is represented by vector 02. Vector 02 is plotted with reference to the position of vector 01 at $t = 0$. When vector 02 comes into existence, vector 01 as well as the vector of potential have advanced in phase by an amount equal to the product of the frequency and time interval $2\ l/v$, in this instance 22.5 degrees. Vector 02 is the resultant of adding the vector of reflected current to the vector of initial current. After an interval of time equal to $6\ l/v$, vector 03 comes into existence and determines the current for the interval of time between $6\ l/v$ and $8\ l/v$. The

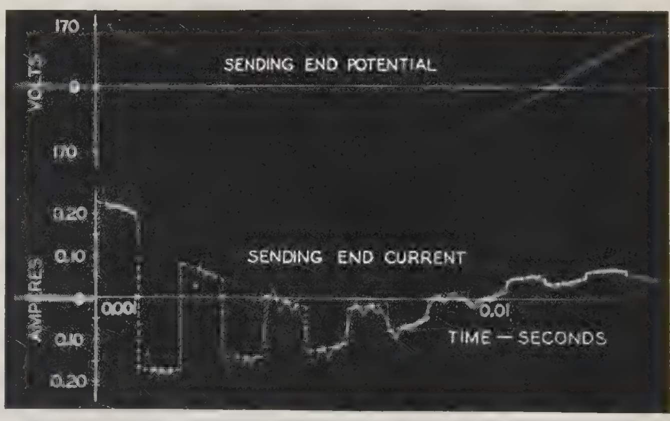


Fig. 4. Transient current on open-circuited line with alternating potential applied; switching angle 112.5 degrees

Dotted curve shows calculated transient

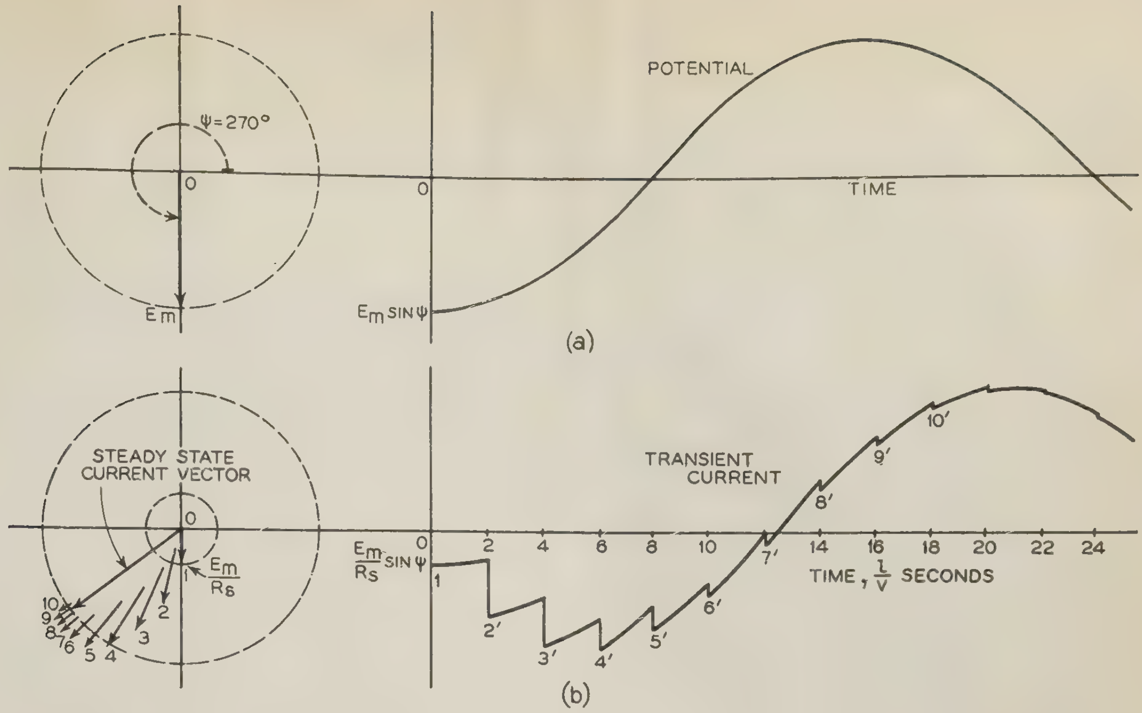


Fig. 5. Calculation of transient on short-circuited line; switching angle 270 degrees

current vectors come into existence with a phase progressively lagging the potential vector. In approximately 0.02 second the steady state current is reached, lagging the potential by approximately 60 degrees.

Figure 6 shows the computation of the transient current at the sending end of the same line open-circuited when a 120-volt 60-cycle potential is impressed. The switching angle is 112.5 degrees so that the potential is applied 22.5 degrees after maximum positive value. For the first interval of time the current is given by the potential divided by the surge resistance, the current vector being 01. After a time interval $2\,l/v$, the reflected current wave from the receiving end, negative in polarity, reaches the sending end. It immediately is doubled in value at the sending end, being represented in phase and magnitude by vector $0R$. Vector $0R$ is combined with vector 01 (now advanced to position 01″) to give the vector of current 02′ for the interval between $2\,l/v$ and $4\,l/v$. To simplify the diagram, vectors 02, 03, 04, etc., are all plotted with reference to vector 01 at $t = 0$. These vectors come into existence with a phase relationship alternately leading and lagging the potential vector. In approximately one cycle, the steady state current is reached, leading the potential by approximately 60 degrees.

Appendix—Mathematical Solution for the Transient State of a Distortionless Line

In the following derivation no restriction is placed on the shape or frequency of the impressed potential $E(t)$. The differential equations are set up by applying the first and second laws of Kirchoff to a differential length of line dx and obtaining in Heaviside notation

$$-\frac{\partial e}{\partial x} = (R + pL)i \tag{1}$$

$$-\frac{\partial i}{\partial x} = (G + pC)e \tag{2}$$

Combining equations 1 and 2 there results

$$\frac{\partial^2 e}{\partial x^2} = (R + pL)(G + pC)e \tag{3}$$

Since in a distortionless line the parameters are related such that

$$\frac{R}{L} = \frac{G}{C} = \delta, \text{ attenuation constant of line} \tag{4}$$

equation 3 reduces to

$$\frac{\partial^2 e}{\partial x^2} = LC(\delta + p^2)e \tag{5}$$

the general solution of which is

$$e = A\epsilon^{\frac{x}{v}(\delta+p)} + B\epsilon^{-\frac{x}{v}(\delta+p)} \tag{6}$$

where A and B are the integration constants to be evaluated from the terminal conditions.

Solution for the current is obtained by substituting equation 6 in equation 1 and obtaining

$$i = -\frac{1}{R + pL}\frac{\partial e}{\partial x}$$

$$= -\frac{1}{R_s}\left[A\epsilon^{\frac{x}{v}(\delta+p)} - B\epsilon^{-\frac{x}{v}(\delta+p)}\right] \tag{7}$$

where

$$R_s = \sqrt{\frac{L}{C}} = \frac{e}{i} \tag{8}$$

and

$$Ce^2 = Li^2 \tag{9}$$

To evaluate constants A and B, 2 terminal conditions are necessary. It is assumed that a potential $E(t)\mathbf{1}$ is impressed suddenly at the sending end, and the receiving end is terminated in an impedance represented by $Z_0(p)$. At the sending end ($x = 0$),

$$A + B = E(t)\mathbf{1} \tag{10}$$

At the receiving end ($x = l$),

$$A\epsilon^{\frac{l}{v}(\delta+p)} + B\epsilon^{-\frac{l}{v}(\delta+p)} = -\frac{Z_0(p)}{R_s}\left[A\epsilon^{\frac{l}{v}(\delta+p)} - B\epsilon^{-\frac{l}{v}(\delta+p)}\right] \quad (11)$$

Solving equations 10 and 11 simultaneously gives

$$A = \frac{\left(1-\frac{Z_0(p)}{R_s}\right)\epsilon^{-\frac{l}{v}(\delta+p)}}{\left(1-\frac{Z_0(p)}{R_s}\right)\epsilon^{-\frac{l}{v}(\delta+p)} - \left(1+\frac{Z_0(p)}{R_s}\right)\epsilon^{\frac{l}{v}(\delta+p)}} E(t)\mathbf{1} \quad (12)$$

$$B = \frac{\left(1+\frac{Z_0(p)}{R_s}\right)\epsilon^{-\frac{l}{v}(\delta+p)}}{\left(1-\frac{Z_0(p)}{R_s}\right)\epsilon^{-\frac{l}{v}(\delta+p)} - \left(1+\frac{Z_0(p)}{R_s}\right)\epsilon^{\frac{l}{v}(\delta+p)}} E(t)\mathbf{1} \quad (13)$$

Substituting the values of A and B in the general solution for potential and current and taking

$$\frac{1-\frac{Z_0(p)}{R_s}}{1+\frac{Z_0(p)}{R_s}} = \frac{R_s - Z_0(p)}{R_s + Z_0(p)} = K, \text{ reflection factor} \quad (14)$$

$$e(x, t) = \frac{\epsilon^{-\frac{x}{v}(\delta+p)} - K\epsilon^{-\frac{2l-x}{v}(\delta+p)}}{1 - K\epsilon^{-\frac{2l}{v}(\delta+p)}} E(t)\mathbf{1} \quad (15)$$

$$i(x, t) = \frac{\epsilon^{-\frac{x}{v}(\delta+p)} + K\epsilon^{-\frac{2l-x}{v}(\delta+p)}}{1 - K\epsilon^{-\frac{2l}{v}(\delta+p)}} \frac{1}{R_s} E(t)\mathbf{1} \quad (16)$$

Equations 15 and 16 are the solutions for the transient potential and current. To obtain the power series form of the solution, divide the numerator by the denominator, obtaining

$$e(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} - K\epsilon^{-\frac{2l-x}{v}(\delta+p)} + K\epsilon^{-\frac{2l+x}{v}(\delta+p)} - K^2\epsilon^{-\frac{4l-x}{v}(\delta+p)} + K^2\epsilon^{-\frac{4l+x}{v}(\delta+p)} - K^3\epsilon^{-\frac{6l-x}{v}(\delta+p)} + K^3\epsilon^{-\frac{6l+x}{v}(\delta+p)} \ldots\right] E(t)\mathbf{1} \quad (17)$$

$$i(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} + K\epsilon^{-\frac{2l-x}{v}(\delta+p)} + K\epsilon^{-\frac{2l+x}{v}(\delta+p)} + K^2\epsilon^{-\frac{4l-x}{v}(\delta+p)} + K^2\epsilon^{-\frac{4l+x}{v}(\delta+p)} + K^3\epsilon^{-\frac{6l-x}{v}(\delta+p)} + K^3\epsilon^{-\frac{6l+x}{v}(\delta+p)} \ldots\right] \frac{1}{R_s} E(t)\mathbf{1} \quad (18)$$

The first term in each equation represents the direct wave and the remaining terms the reflections. Equations 17 and 18 may be written

$$e(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} - \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml-x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml+x}{v}(\delta+p)}\right] E(t)\mathbf{1} \quad (19)$$

$$i(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml-x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml+x}{v}(\delta+p)}\right] \frac{1}{R_s} E(t)\mathbf{1} \quad (20)$$

Special Case: Alternating Potential Impressed

Let an alternating potential be applied suddenly to the line. Its expression in complex notation is

$$E(t) = E_m\epsilon^{j(\omega t+\psi)} \quad (21)$$

and the direct and reflected waves are damped sinusoids. The equations for the direct wave are

$$e = \epsilon^{-\frac{x}{v}(\delta+p)} E(t)\mathbf{1} = \epsilon^{-\frac{x}{v}(\delta+j\omega)} E_m\epsilon^{j(\omega t+\psi)} \quad (22)$$

$$i = \epsilon^{-\frac{x}{v}(\delta+p)} \frac{1}{R_s} E(t)\mathbf{1} = \epsilon^{-\frac{x}{v}(\delta+j\omega)} \frac{E_m}{R_s}\epsilon^{j(\omega t+\psi)} \quad (23)$$

The amplitudes of oscillation of potential and current in the direct wave at point x_1 in the line are

$$E_{mx1} = E_m\epsilon^{-\frac{x_1}{v}\delta} \quad (24)$$

$$I_{mx1} = \frac{E_m}{R_s}\epsilon^{-\frac{x_1}{v}\delta} \quad (25)$$

The equation for potential including the reflections becomes

$$e(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} - \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml-x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml+x}{v}(\delta+p)}\right] E_m\epsilon^{j(\omega t+\psi)}\mathbf{1} \quad (26)$$

and in the steady state, replacing p by $j\omega$,

$$e(x) = \left[\epsilon^{-\frac{x}{v}(\delta+j\omega)} - \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml-x}{v}(\delta+j\omega)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml+x}{v}(\delta+j\omega)}\right] E_m\epsilon^{j(\omega t+\psi)} \quad (27)$$

$$e(x) = \left[\cosh(\sqrt{RG} + j\omega\sqrt{LC})x - (1 + 2\sum_{m=1}^{m=\infty} K^m\epsilon^{-(\sqrt{RG}+j\omega\sqrt{LC})2ml})\sinh(\sqrt{RG} + j\omega\sqrt{LC})x\right] E_m\epsilon^{j(\omega t+\psi)} \quad (28)$$

so that for effective values

$$E(x) = E\cosh(\sqrt{RG} + j\omega\sqrt{LC})x - IR_s\sinh(\sqrt{RG} + j\omega\sqrt{LC})x \quad (29)$$

Similarly the equation for the current including the reflections is

$$i(x, t) = \left[\epsilon^{-\frac{x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml-x}{v}(\delta+p)} + \sum_{m=1}^{m=\infty} K^m\epsilon^{-\frac{2ml+x}{v}(\delta+p)}\right] \frac{1}{R_s} E_m\epsilon^{j(\omega t+\psi)}\mathbf{1} \quad (30)$$

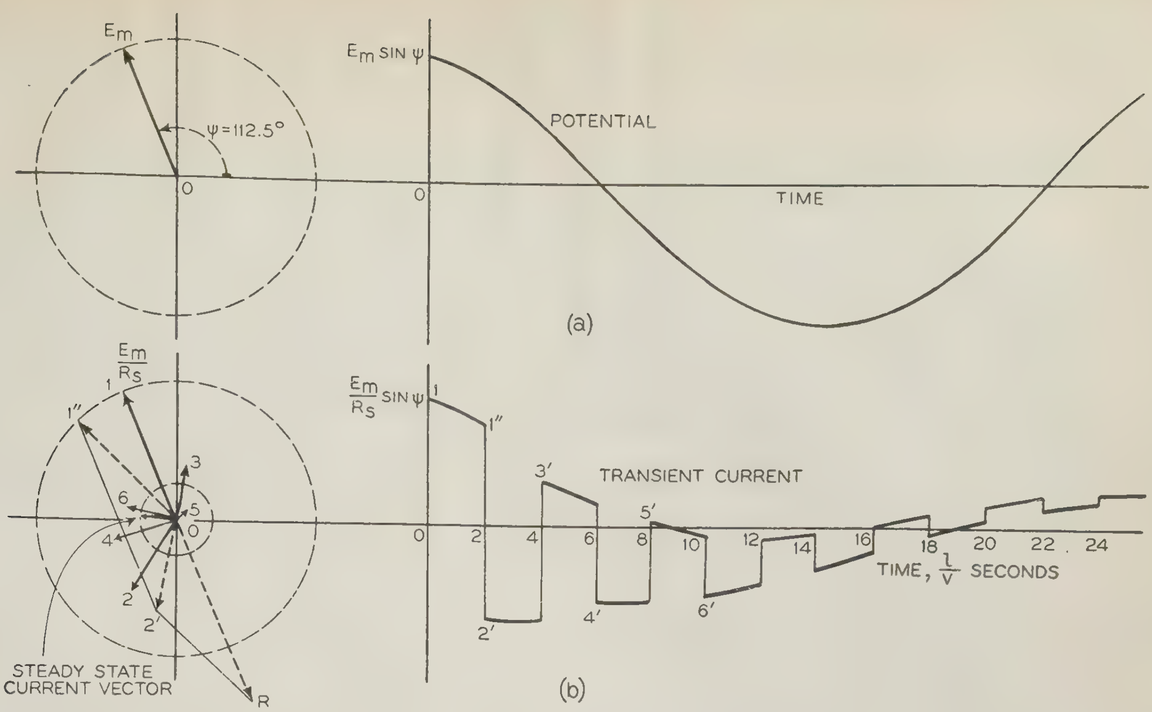
and in the steady state

$$i(x) = \left[(1 + 2\sum_{m=1}^{m=\infty} K^m\epsilon^{-(\sqrt{RG}+j\omega\sqrt{LC})2ml})\cosh(\sqrt{RG} + j\omega\sqrt{LC})x - \sinh(\sqrt{RG} + j\omega\sqrt{LC})x\right] \frac{1}{R_s} E_m\epsilon^{j(\omega t+\psi)} \quad (31)$$

so that for effective values

$$I(x) = I\cosh(\sqrt{RG} + j\omega\sqrt{LC})x - \frac{E}{R_s}\sinh(\sqrt{RG} + j\omega\sqrt{LC})x \quad (32)$$

Fig. 6. Calculation of transient on open-circuited line; switching angle 112.5 degrees



The connection between equations 28 and 29 and between equations 31 and 32 is the factor F which is the quotient of the vectors of steady state current and the initial current wave, both referred to the sending end of the line.

$$F = 1 + 2 \sum_{m=0}^{m=\infty} K^m \epsilon^{-(\sqrt{RG}+j\omega\sqrt{LC})2ml} \tag{33}$$

$$= 1 + 2 \sum_{m=1}^{m=\infty} K^m \epsilon^{-2m\theta} \tag{34}$$

where

$$\theta = (\sqrt{RG} + j\omega\sqrt{LC})l \tag{35}$$

$$F = \frac{1 + K\epsilon^{-2\theta}}{1 - K\epsilon^{-2\theta}} \tag{36}$$

$$= \frac{Z_0(j\omega)\sinh\theta + R_s\cosh\theta}{Z_0(j\omega)\cosh\theta + R_s\sinh\theta} \tag{37}$$

$$= \frac{I}{(E/R_s)} \tag{38}$$

the last step being obtained from the general steady state equations

$$E = E_l\cosh\theta + I_l R_s\sinh\theta \tag{39}$$

$$I = \frac{E_l}{R_s}\sinh\theta + I_l\cosh\theta \tag{40}$$

Special Case: Continuous Potential Impressed

If a continuous potential be applied suddenly to a line

$$E(t) = E1 \tag{41}$$

and the direct and reflected waves are d-c surges damped exponentially along the line. The equation for potential including the reflections becomes

$e(x, t) =$

$$\left[\epsilon^{-\frac{x}{v}\delta} - \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml-x}{v}\delta} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml+x}{v}\delta}\right] E1 \tag{42}$$

and in the steady state

$e(x) =$

$$\left[\cosh\sqrt{RG}x - \left(1 + 2\sum_{m=1}^{m=\infty} K^m \epsilon^{-\sqrt{RG}\,2ml}\right)\sinh\sqrt{RG}x\right]E \tag{43}$$

$$e(x) = E\cosh\sqrt{RG}x - IR_s\sinh\sqrt{RG}x \tag{44}$$

Similarly for the current

$i(x, t) =$

$$\left[\epsilon^{-\frac{x}{v}\delta} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml-x}{v}\delta} + \sum_{m=1}^{m=\infty} K^m \epsilon^{-\frac{2ml+x}{v}\delta}\right]\frac{1}{R_s}E1 \tag{45}$$

and in the steady state

$$i(x) = \left[\left(1 + 2\sum_{m=1}^{m=\infty} K^m \epsilon^{-\sqrt{RG}\,2ml}\right)\cosh\sqrt{RG}x - \sinh\sqrt{RG}x\right]\frac{1}{R_s}E \tag{46}$$

$$i(x) = I\cosh\sqrt{RG}x - \frac{E}{R_s}\sinh\sqrt{RG}x \tag{47}$$

Equations 44 and 47 are the well-known equations of the steady state obtained by solving the differential equations for an element of line in the steady state.

References

1. Electrical Papers, v. 2, and Electromagnetic Theory, v. 2, O. Heaviside. Ernest Benn Ltd., London.

2. Electric Circuit Theory and Operational Calculus, J. R. Carson. McGraw-Hill Book Co., N. Y.

3. Traveling Waves on Transmission Systems, L. V. Bewley. John Wiley and Sons, N. Y.

4. A Graphical Theory of Traveling Waves, V. Karapetoff. A.I.E.E. Trans., v. 48, 1929, p. 508–22.

5. Elektromagnetische Ausgleichsvorgange in Freileitungen und Kabeln, K. W. Wagner. B. G. Teubner, Leipzig.

6. The Building-Up of Sinusoidal Currents in Long Periodically Loaded Lines, J. R. Carson. *Bell System Tech. Jl.*, Oct. 1924, p. 558–66.

7. Theory of Transient Oscillations of Electrical Networks and Transmission Systems, J. R. Carson. A.I.E.E. Trans., v. 38, 1919, p. 345–427.

8. Telephone Transmission Over Long Cable Circuits, A. B. Clark. A.I.E.E. Jl., v. 42, Jan. 1923, p. 86–96.

The Electrochemical Industry in Japan

A brief outline of the status of the electrochemical and electrometallurgical industry in Japan, including some figures on the production of various materials which have been obtained in recent years, is given here.

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NOT being affected by the economic depression which has influenced so much of the world, most of the manufacturing industries in Japan have made steady progress during recent years. Among these, the electrochemical industry is the one which has progressed most rapidly. An attempt to illustrate the present size of this industry in Japan will be made in this article. It may be a surprising statement, but the total annual value of the products of the electrochemical industry in Japan amounts to nearly 300,000,000 yen ($90,000,000).

Hydroelectric power may be regarded as an important necessity for this industry. Fortunately, the country is well provided with such power, and until recently Japan had a surplus of hydroelectric power. At present, however, the rapid progress of the industry has placed the country in quite a different situation, and many new power stations are now being erected throughout the country. It is estimated that the total electric power actually generated now amounts to 3,000,000 kw, although the total capacity of the generating plants is much greater. Among these, the hydroelectric power plants predominate.

Size of Electrochemical Industry

The electrochemical industry, as already mentioned, has made good progress. New plants have been erected, and the capacities of old ones have been increased. An idea of the approximate sizes of some branches of the industry may be obtained from table I, the second column of which shows the total installed electric power capacity for these branches. The total capacities of these industries thus amount to nearly 1,000,000 kva. However, they are not operated at full capacity. Some are operated throughout the year only during the daytime, and others are operated only in the summer season. Their actual power consumption, therefore, is of course less than the above figure, the power actually used being shown in the third column of table I.

It may be of interest to note that especially large amounts of power are used in the manufacture of calcium carbide and in the electrolysis of water. This is due mainly to the fact that water power is available in some localities.

From what has been said, the electric power actually used in the electrochemical industry in Japan may be estimated at more than 500,000 kw. Almost all kinds of electrochemical products that are made elsewhere in the world are produced in that country. The principal products and their approximate annual production are shown in table II.

Production of Various Products

Manufacture of calcium carbide is one of the oldest electrochemical industries in Japan, and many years of training in its manufacture have been obtained. The plants are located mainly in mountanous districts; these plants are shown by the solid dots in figure 1. Most of the carbide is converted into calcium cyana-

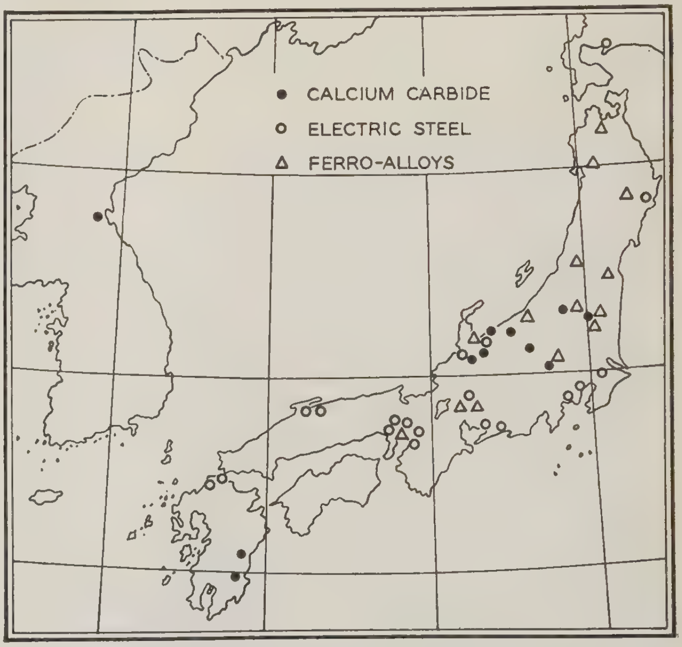

Fig. 1. Locations of plants for the production of calcium carbide, electric steel, and ferroalloys

Table I—Installed Capacity and Power Consumption in the Electrochemical Industry

Kinds of Industry	Total Capacities Installed (Kva)	Actual Power Consumption (Kw)
Manufacture of calcium carbide	320,000	110,000
Manufacture of steel	200,000	100,000
Manufacture of ferroalloys, etc.	100,000	30,000
Electrolysis of water	220,000	200,000
Electrolysis of sodium chloride	40,000	22,000
Metal refining	20,000	15,000

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mide which is used directly as a fertilizer while a portion of it is converted to acetic acid. Many attempts now are being made to utilize carbide and cyanamide for making new chemicals.

Manufacture of steel by the electric furnace is now quite common. Remarkable progress has been made in the construction of the furnace, and production of steel has increased remarkably since 1930, as shown in table III.

Production of ferroalloys, such as ferrochrome, ferrosilicon, and ferromanganese also is increasing. The production of low carbon ferrochrome is particularly successful. Some ferroalloys now are exported.

Table II—Annual Production of Various Products in 1934

Products	Annual Production in Tons
Calcium carbide	250,000
Electric steel	170,000
Ferroalloys	40,000
Ammonium sulphate	1,000,000
Electrolytic caustic soda	80,000
Electrolytic copper	70,000
Electrolytic zinc	6,000

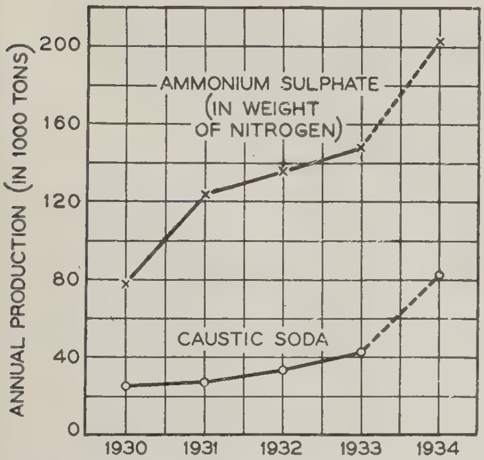

Fig. 2. Production of ammonium sulphate and electrolytic caustic soda

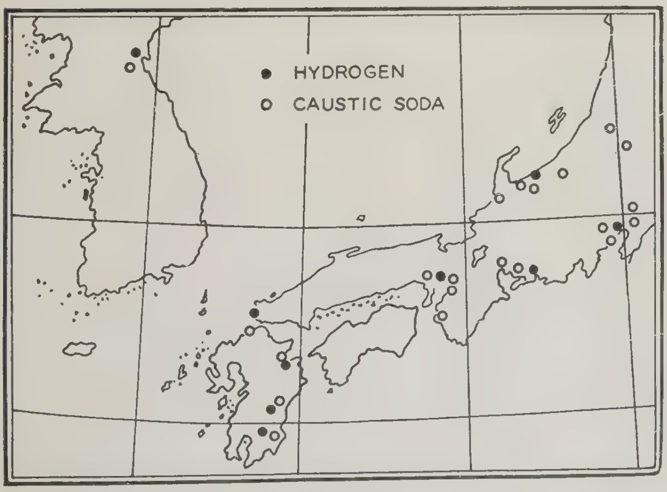

Fig. 3. Locations of plants for the production of electrolytic hydrogen and electrolytic caustic soda

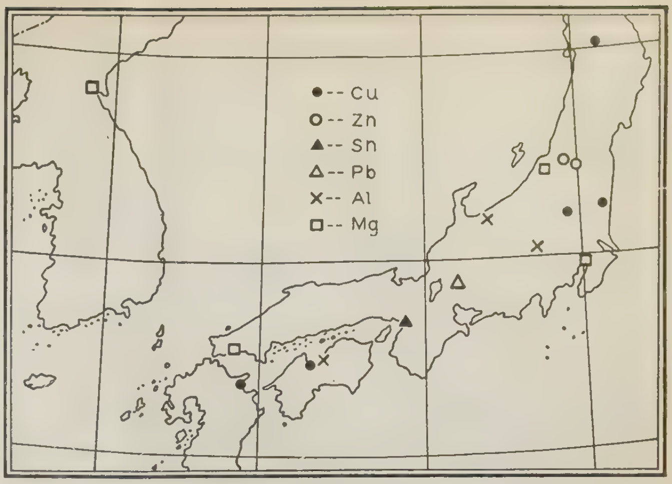

Fig. 4. Locations of plants for the electrolytic production of various metals

Table III—Production of Steel by Electric Furnaces

Year	Annual Production of Electric Steel in Tons
1930	62,140
1932	69,704
1933	137,600
1934	nearly 170,000

Plants for the production of electric steel and ferroalloys are also located mainly in the mountainous districts in order to use cheap water power; these plants are shown by the open circles and triangles in figure 1.

Several large plants have been set up recently for the synthesis of ammonium sulphate. Most of the hydrogen used for this purpose is produced by the electrolysis of water. The production of ammonium sulphate has increased remarkably during the last 2 years, as shown in figure 2. Japan imported large quantities of ammonium sulphate until a few years ago, but now the country is in a position to export this product.

Production of caustic soda and chlorine by electrolysis also has increased very rapidly, as shown in figure 2. Many existing plants have been enlarged. Also, a few large plants for the manufacture of artificial silk have begun production for their own use. The production of electrolytic caustic soda is estimated to have been more than 80,000 tons in 1934. Locations of plants for the production of electrolytic hydrogen and caustic soda are shown in figure 3. These plants are not limited to the mountainous districts.

Production and Refining of Metals

The refining of copper by electrolysis is very popular in Japan. Most of the crude copper produced by the dry method is treated electrochemically and gold and silver are recovered. Owing to the rise in the value of gold, this industry is now in a good condition.

The refining of tin and lead also is considered to

be very promising, but their production at present is not large. This is due mainly to the lack of good ore. The obtaining of zinc by electrolytic means also is successful, and production is increasing yearly.

Aluminum and magnesium were not produced in Japan until recently, owing to the lack of suitable raw materials. Success in their production now has been obtained by applying Japanese-developed processes and using Japanese materials. Some products of these materials already are found in the market, and in the near future, it appears that overproduction may be suffered.

Locations of plants for obtaining metals electrolytically are shown in figure 4.

Recently, the discovery of nickel and cobalt ores has been reported. In the near future, it appears that the electrometallurgy of these metals will be accomplished in Japan. Beside these, there are many products such as chlorate, perchlorate, and persulphate, which are produced. The production of dry batteries and secondary batteries is steadily increasing, and a fairly large number of dry batteries is now exported. Thus, in most of the electrochemical and electrometallurgical industries, the country is placed in a position to be more than self-supporting. However, for the development of these industries the country owes a great deal to what has been learned from other nations, and still wishes to learn more.

Japanese discoveries and inventions are increasing very rapidly. It is now estimated that Japan ranks third in the world as far as the number of patents is concerned. Also, there are societies and associations in all branches of science and industry, and with many members. Consequently, it is hoped to exchange knowledge and experience in this field with other nations, and to enjoy co-operation.

Surge Protectors for Current Transformers

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Surge protection and open-circuit protection of current transformers may be obtained by the application of shunts in which the material known as "thyrite," and which has a negative resistance characteristic, is used. The surge protector is connected across the current transformer primary, and the open-circuit protector across the secondary. Voltages across the current transformer winding are considerably reduced by the use of these protectors, with negligible effect upon the transformer accuracy during normal operating conditions, and without impairing safe operation of relays during system faults.

IN the application of current transformers on high voltage circuits it is desirable that some sort of by-pass be provided as a protection against abnormal surges. It is also well known that the secondary of a current transformer cannot be opened without the risk of excessively high voltages appearing across the windings, which voltages may puncture the winding and overheat the core.

A conventional by-pass protector, figure 1, in use for many years on high voltage current transformers, consisted of a vacuum gap in series with a resistance rod to limit the follow current so as to quench the arc. In addition, there was a simple knurled gap shunting the above vacuum gap, and the whole was enclosed in a weather proof glass jar. In good condition these by-pass protectors were quite adequate for the purpose intended, and about all that can be said against them is that they were bulky and there was the possibility of the gaps becoming fouled.

In the past, current transformers were not sold with protection against an open-circuited secondary, although short-circuiting links were provided when the burden was to be disconnected purposely. Nevertheless, sometimes a small spring gap with a cigarette paper separator, or a film cut-out, was used to protect against an accidental opening of the secondary. On low voltage current transformers, vacuum tubes and relays have been used.

Figure 2 shows the diagram of connections for a current transformer with shunts of "thyrite" (a material the resistance of which decreases with increasing voltage and current) across both the primary and secondary windings, giving protection against either surges or open-circuited secondary. In addition, a neon lamp indicator is shown for indicating an open-circuit condition.

The surge protector for the primary is mounted as

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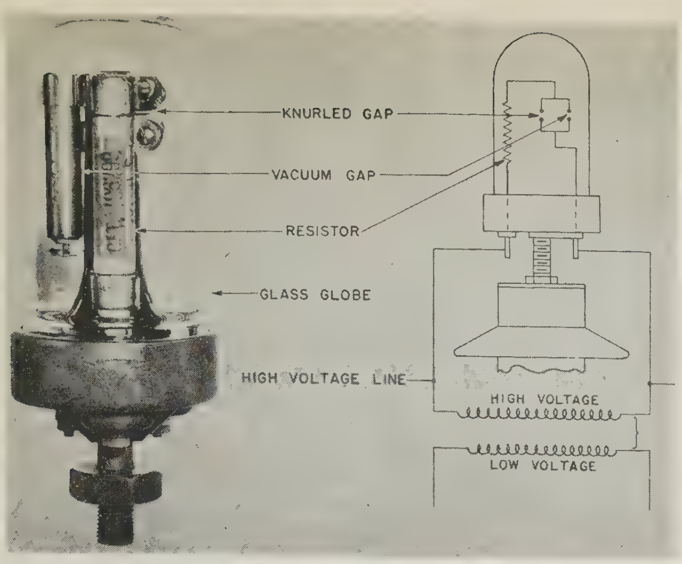


Fig. 1. Old conventional type by-pass for current transformers

an integral part of the unit, as shown in figure 3, and usually consists of a thyrite piece 3 inches in diameter and from a fraction of an inch to several inches thick. The thyrite is attached to the cover, which, when in position, contacts a spring connector to the other lead.

The secondary protector and its neon lamp indicator, figure 4, are usually mounted external to the current transformer proper, in order to facilitate the heat dissipation. It consists of a number of thin thyrite disks with center holes, mounted on a rod and electrically connected in parallel. The large copper plates function as cooling fins.

The conclusions which may be drawn from the information presented in this paper are as follows:

Thyrite Surge Protector

1. If a current transformer without a by-pass is connected to a bus or power transformer, the circuit behaves under surge conditions as an inductance (the current transformer) connected in series with a capacitance (the bus or power transformer), and the voltage on the bus side will oscillate to nearly double the surge voltage on the line side of the current transformer. This results in nearly the total surge voltage appearing across the current transformer winding.

2. The addition of a thyrite by-pass across the primary of the current transformer prevents the oscillation, and consequently the bus surge voltage does not exceed the line surge voltage appreciably.

3. The by-pass prevents the concentration of surge voltage across the current transformer, and is more effective in this respect the higher the surge voltage.

4. The by-pass is designed to operate indefinitely without overheating for either a short circuit on the primary side or a disconnected burden on the secondary side.

5. The current by-passed under normal operating conditions is entirely insignificant and does not affect the accuracy.

Thyrite Open-Circuit Protector

1. The open-circuit protector is designed to limit the maximum voltage across the secondary with a disconnected burden, to approximately 100 volts (effective).

2. The effect on ratio and phase-angle accuracy is negligible under normal operating conditions between 5 and 100 per cent load current, and therefore this device can be applied to current transformers already in service.

3. On over-loads, the ratio and phase-angle errors are increased by the thyrite protector, but these increased errors are not so large as to impair the safe operation of overcurrent or differential relays.

4. The open-circuit protector is designed to operate indefinitely without over-heating.

Design Conditions

The protective devices must fulfill the following conditions:

1. The amount of current by-passed under normal operating conditions must not be such as to affect the accuracy of the current readings. The by-pass current therefore has been limited to less than 0.05 per cent of the transformer current rating.

2. The shunt resistors must operate indefinitely without overheating, for either a short circuit on the primary side or a disconnected burden on the secondary side.

3. The maximum permissible voltage across the secondary with a disconnected burden, has been arbitrarily fixed at 100 volts.

4. The impulse voltage across the primary winding for the maximum surge that can be impressed, must not exceed the safe value for the insulation.

The influence of the above factors on the design of the surge protector and open-circuit protector will now be considered in detail.

Design of Surge Protector

The present A.I.E.E. rules specify that the current transformer shall stand a short-circuit current of 60 times its normal rating for 2 seconds without overheating. The corresponding potential difference across the current transformer is then one limit which determines the minimum thickness of thyrite neces-

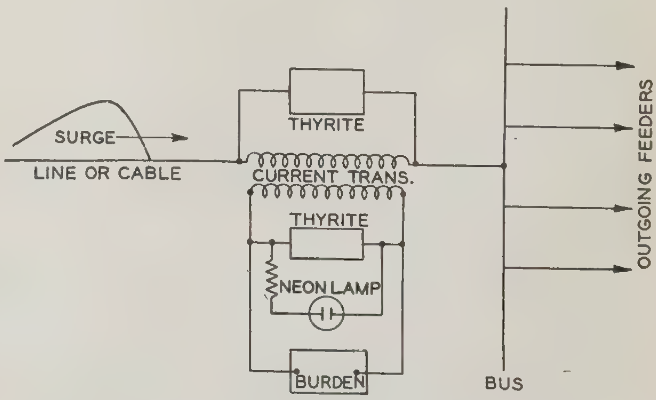


Fig. 2. Diagram of connections for a current transformer with thyrite shunts across both the primary and secondary windings, giving protection against either surges or open-circuited secondary

sary in the shunt, unless a series gap is employed. If a series gap is provided for the purpose of avoiding this heating limitation, then the gap spark-over must have a definite margin over the short-circuit voltage, and there must be enough thyrite in series to cause positive sealing of the gap at a voltage higher than the short-circuit voltage; for otherwise there exists the possibility of a surge causing a gap

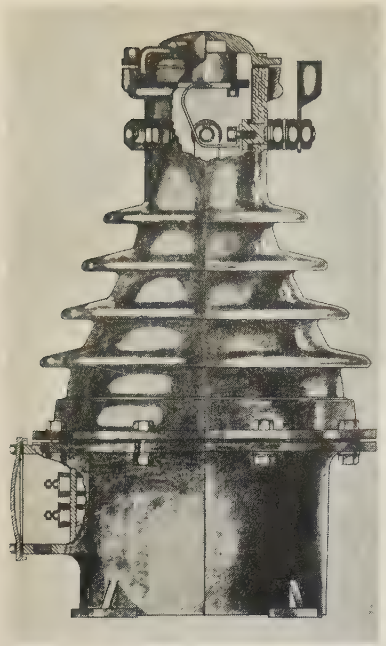


Fig. 3. The thyrite shunt type of surge protector for the primary

spark-over, and then while the gap is bridged, the system may be short circuited by a line-to-ground flashover. If this happened, and the gap did not seal at the short-circuit voltage, the thyrite would overheat.

The curves of figure 5 give the short-time temperature rise above 25 degrees centigrade ambient for thyrite disks 3 inches in diameter by 1 inch thick, for natural air draft circulation and no radiating fins. The minimum thickness of thyrite that can be used to prevent over-heating is then

$$L = \frac{\text{short-circuit voltage across current transformer}}{\text{(volts/inch) for } T \text{ degrees temperature rise in } t \text{ seconds}}$$

$= 0.7$ (kv) for 80 degrees and 2 seconds

Appropriate heating curves for thyrite in oil are also available.

The peak voltage due to an open-circuited secondary may exceed that due to a short circuit, but due to saturation effect, the former is a slender needle of voltage and is not ordinarily a limitation as far as heating is concerned.

Having fixed the minimum length of thyrite as determined from the system short-circuit heating limitations, the next step is to find the diameter which will limit the voltage across the primary to a safe value for any surge that can appear on the system. This is essentially the same kind of problem as is met in applying shunt resistors for current limiting reactors. (See reference 1 at end of paper.) Of course, the voltage that can appear across the primary winding depends upon the terminal connections. If the current transformer is connected to a large bus with several outgoing feeders, then the voltage across the winding due to a surge coming in on the incoming line will be greater than if the transformer were merely inserted in the line. But in any event, as far as voltage across the winding is concerned, the worst condition would be with the end of the winding grounded. This is easily seen as follows. Consider a line of surge impedance Z terminating in 2 resistances r and R in series. Then for a traveling wave E the voltage across the first resistance r is

$$e = 2E\left(\frac{r}{Z + r + R}\right)$$

and this obviously is a maximum for $R = 0$

Therefore, in designing the thyrite shunt, one end is regarded as grounded, and the winding itself as open circuited. From this conservative point of view the thyrite shunt is simply equivalent to a thyrite lightning arrester, and the voltage across the thyrite is

$$e = KI^{(1-n)} = 2E - ZI \qquad (1)$$

where

E = magnitude of the incoming surge as limited by the system insulation (it is proposed that E be based upon the insulator flashover for a comparatively short wave. The 1 x 5 microsecond impulse wave is suggested and used in the calculations of this article)
Z = surge impedance of the line (or cable)
I = current in the surge
n = a characteristic constant of thyrite depending upon the ingredients
K = a characteristic constant of thyrite depending upon the ingredients and dimensions
$= kL/D^{2(1-n)}$; where L = length, D = diameter, and k = constant of the material

Equation 1 can be solved either graphically or by trial, but for the present purposes, advantage can be taken of the fact that the thyrite resistance will be so small compared with the surge impedance of the line that for all practical purposes

$$I = \frac{2E}{Z} \qquad (2)$$

$$\therefore e = KI^{(1-n)} = K\left(\frac{2E}{Z}\right)^{(1-n)} = \frac{kL}{D^{2(1-n)}}\left(\frac{2E}{Z}\right)^{(1-n)} = kL\left(\frac{2E}{ZD^2}\right)^{(1-n)} \qquad (3)$$

As an example let:

Short circuit voltage = 3,500 volts for 2 seconds
Normal voltage = 50 volts across primary.
Z = 500 ohms surge impedance of line
n = 0.72, k = 2,100 } thyrite constants
e = 25,000 volts
E = 500 kv (insulator flashover of 4 standard insulator disks on the 1 x 5 microsecond wave)

From the heating curves, for an 80 degree rise in 2 seconds, the minimum length of thyrite is

$$L = 0.7 \times \frac{3{,}500}{1{,}000} = 2.5 \text{ inches}$$

By equation 3

$$25{,}000 = 2{,}100 \times 2.5\left(\frac{1{,}000{,}000}{500 \times D^2}\right)^{0.28}$$

Therefore,

$D = 2.78$ (say, 3 inches)

Thus a thyrite shunt having a diameter of 3 inches and a thickness of $2^1/_2$ inches will not overheat on

system short circuit, and will limit the impulse voltage across the current transformer to 25 kv.

The current by-passed at normal voltage is of the order of 2×10^{-4} amperes, and thus entirely insignificant.

Design of Open-Circuit Protector

The design of the thyrite shunt across the secondary for open-circuit protection is based upon the maximum allowable voltage, the heating, and the permissible by-pass current at normal voltage. The maximum allowable open-circuit voltage has been

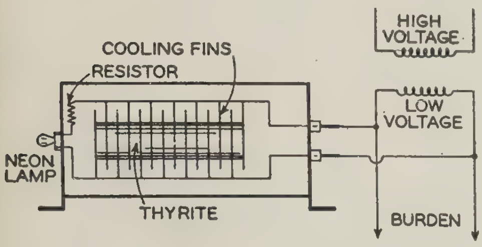


Fig. 4. The open - circuit protector, consisting of thyrite shunt and neon lamp across current transformer secondary

arbitrarily taken as 100 volts (effective). A heating limit of 100 degrees centigrade rise is permissible on continuous open-circuit operation at normal primary load, or for 2 seconds system short circuit. The permissible by-pass current under normal conditions is fixed at 0.05 per cent of the secondary current rating.

When the burden is disconnected, the thyrite shunt across the secondary comprises the only load on the current transformer, and by equation 3 the voltage and current are related by

$$e = Ki^{(1-n)} \tag{4}$$

But the volt-ampere characteristic of the current transformer is some function of the primary current I and the secondary current i

$$e = f(i, I) \tag{5}$$

and the function $f(i, I)$ can be determined from test,

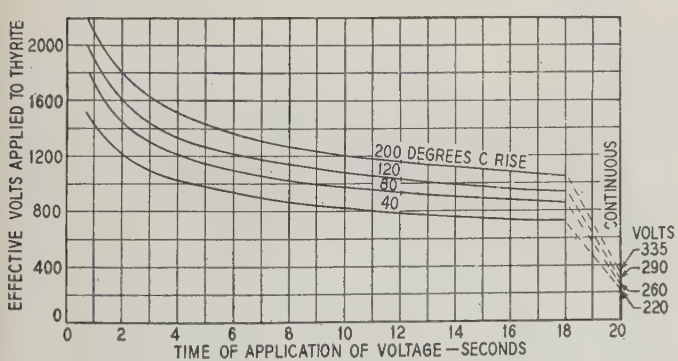


Fig. 5. Calculated voltage-time curves based upon thyrite disks 3 inches in diameter by 1 inch thick

All temperature rises based upon disk without radiating fins and with natural air draft circulation

All temperature rises are above 25 degrees centigrade ambient

Curves are based upon sinusoidal voltage wave forms

or from calculations if the saturation curve is available.

Figure 6 shows a set of these characteristics for a particular transformer, the secondary voltage being plotted against the secondary current with primary load as parameter.

Thus for a specified open-circuit voltage (e = 100 volts) and primary load (I = 100 per cent), the secondary current is found from the volt-ampere characteristic of figure 6. From the thyrite equation, there results, for N disks in parallel:

$$e = K\left(\frac{i}{N}\right)^{(1-n)} = \frac{kL}{D^{2(1-n)}}\left(\frac{i}{N}\right)^{(1-n)} = kL\left(\frac{i}{ND^2}\right)^{(1-n)} \tag{6}$$

or solving

$$ND^2 = i\left(\frac{kL}{e}\right)^{1/(1-n)} \tag{7}$$

As an example let:

e = 115 volts (crest) permissible open-circuit voltage (this corresponds to 100 volts effective)
T = 100 degrees centigrade rise on open-circuit voltage of 100 volts
k = 2,100 } thyrite constants
n = 0.72 }
t = continuous

It has been found from tests on open-circuit protectors that the temperature rise on a 3 inch diameter disk $^1/_8$ inch thick is approximately 100 degrees centigrade with 100 volts (effective) impressed con-

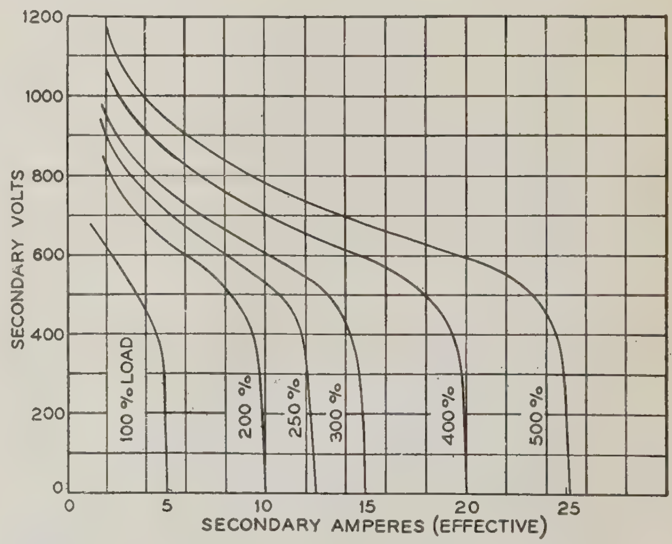


Fig. 6. Volt-ampere characteristics of a particular transformer

tinuously. This is quite permissible on thyrite mounted external to the transformer. The required number of 3 by $^1/_8$ inch thyrite disks is therefore, by equation 7,

$$N = \frac{i}{D^2}\left(\frac{kL}{e}\right)^{\frac{1}{1-n}} = \frac{5 \times \sqrt{2}}{3^2}\left(\frac{2,100 \times 0.125}{115}\right)^{1/0.28}$$

= 15 disks in parallel.

It is necessary to check that these 15 disks will not

by-pass too much current at normal voltage with a burden of 50 volt-amperes.

$$i = N\left(\frac{e}{K}\right)^{\frac{1}{1-n}} = 15\left(\frac{10 \times \sqrt{2}}{142}\right)^{3.57} = 0.004 \text{ amperes (crest)}$$

$$= 0.0029 \text{ amperes (effective)}$$

In order to reduce this figure below the permissible by-pass current of 0.05 per cent the number of disks should be only 13 disks. The open-circuit voltage will then slightly exceed 100 volts effective.

As a matter of fact, the thyrite shunt across the secondary actually improves the accuracy of the current transformer slightly, because while the correction factor for the burden tends to decrease with an increase of load, that for the thyrite tends to increase, so that the resultant correction factor is more flat. This effect can be seen from the correction factor curves of figure 7. It is clear that thyrite shunts can be applied to existing transformers without requiring recalibration.

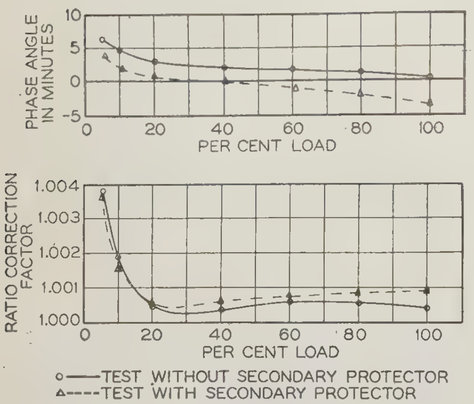


Fig. 7. Correction factors of current transformers with and without the secondary protector

Tests at 50 volt-amperes, 50 per cent power factor, and 60 cycles

The effect of the shunt across the secondary and with the current transformer under short-circuit condition is shown in figure 8. For the great majority of relay applications, the overcurrent ratio and phase-angle characteristics shown in figure 8 are entirely suitable, as a 7 per cent error in ratio at 10 times normal primary current would have no appreciable effect upon the time of induction-type or plunger-type overcurrent relays. The error is well within the limitations imposed by generator, transformer, or bus differential protection. Both generator and transformer differential protective relays have a percentage characteristic that would prevent false operation during external faults when the ratio error of the transformer is 7 per cent.

As a matter of fact, in the case of generator differential protection, it is the *difference* in error between the 2 current transformers that counts, rather than the actual error of either from the marked ratio. The relay to which the errors are the most important is the reactance distance relay which is affected by both ratio and phase angle errors. Fortunately these are in a direction to offset each other to some extent. Also, fortunately the ratio error is somewhat larger than the phase angle error in its effect upon the distance measurement and it is therefore in the safe direction in making the relay under-reach.

The voltage across the secondary is a maximum for the secondary burden disconnected and maximum short-circuit current on the system. At 60 times normal load this maximum voltage is, by equation 6:

$$e_{max} = kL\left(\frac{i}{ND^2}\right)^{(1-n)} = 2{,}100 \times \frac{1}{8}\left(\frac{60 \times 5}{13 \times 9}\right)^{0.28} = 342 \text{ volts}$$

and this may persist for as long as 2 seconds.

The question naturally arises, why not design the shunt across the primary to provide both surge protection and open-circuited secondary protection? But in order for a primary shunt to accomplish this latter mission, it would have to by-pass practically all of the primary current, because on open circuit the core of the current transformer saturates at a fraction of normal primary current and it is this saturation which determines the peak voltage on open circuit.

Design of Open-Circuit Neon Detector

In order to give visual indication of an open circuit of the secondary, it is desirable to have some kind of a device which draws no current on normal voltage. A neon lamp shunting the secondary is ideal for this purpose, as normal voltage is insufficient to cause it to strike. The neon lamp used as an adjunct on current transformers has a striking voltage of approximately 50 to 60 volts, thus does not respond until the voltage rises to 100 volts due either to an open-circuited secondary or to a system short circuit. In order to limit the current through the neon lamp to a safe value during a system short circuit, a ballasting resistor of approximately 100,000 ohms is connected in series with it.

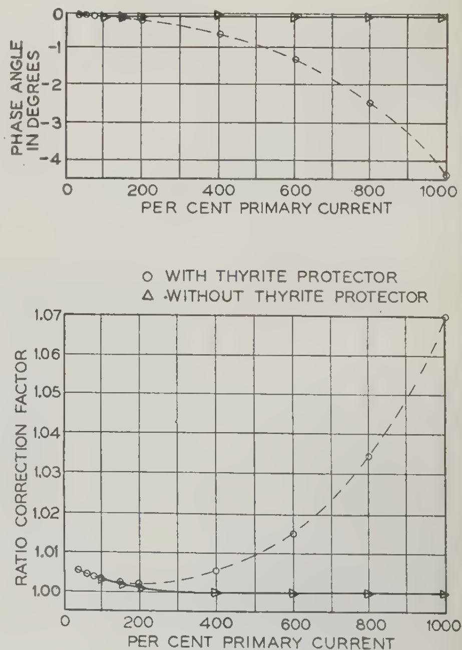


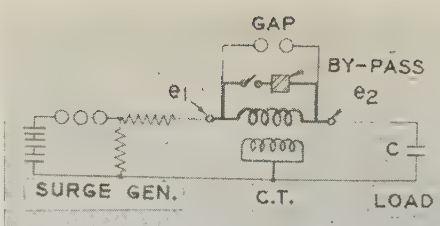
Fig. 8. Correction factors of current transformers, with and without the secondary protector, and with current transformer under overload conditions

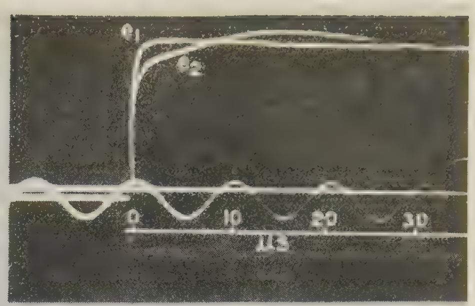
Tests at 50 volt-amperes, 50 per cent power factor, and 60 cycles

The neon lamp is not itself adaptable as a protective device, because in order to stand the heating caused by an open circuit it would have to be excessively large.

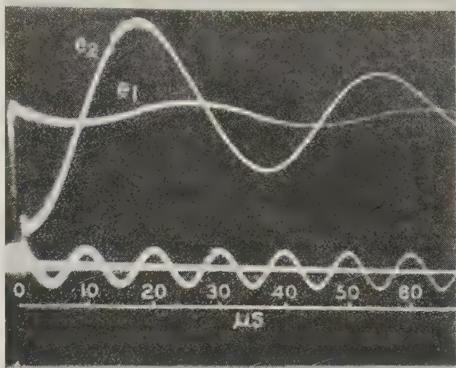
Fig. 9. Connection diagram and representative oscillograms of impulse tests made on a new type of current transformer, to demonstrate the efficacy of the thyrite surge protector

a—25 kv applied Thyrite protector out
b—25 kv applied Thyrite protector in
c—100 kv applied Thyrite protector in
Time scales are in microseconds

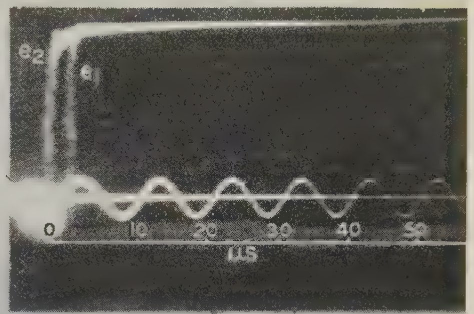




(b)



(a)



(c)

Tests on Surge Protector

To demonstrate the efficacy of the thyrite surge protector, a series of impulse tests was made on a 37 kv current transformer of the new type. Figure 9 shows the connection diagram and representative oscillograms of these tests. A capacitance of 0.001 microfarad was selected as a load to simulate the bus capacitance. The pair of oscillograms at the top, for an applied surge of 25 kv, shows the voltages e_1 and e_2 measured respectively on the impulse generator and load sides of the current transformer. There is a small ripple in the applied voltage e_1 and an appreciable oscillation in the transmitted surge e_2. It will be observed that e_2 does not start at zero, but at a definite voltage. The reason for this was that the through series capacitance of the transformer allowed an initial voltage to be impressed on the load capacitance. A maximum of approximately 75 per cent of the crest of the applied wave appeared across the transformer winding. The bushing flashover on this particular transformer was 200 kv, and a surge of this magnitude impressed on the transformer would have resulted in 150 kv across the winding.

The oscillograms in the middle, for an applied surge of 25 kv, show the very beneficial results of the thyrite by-pass in reducing the voltage across the winding. The by-pass was 3 inches in diameter by $1^7/_8$ inches long. In this case, less than 10 per cent of the applied wave crest appears across the winding.

For higher voltages the case becomes even better for the thyrite by-pass, due to its characteristics, as is evident from the oscillograms for an applied surge of 100 kv. For this voltage there is no appreciable difference between the voltages e_1 and e_2 on the 2 sides of the winding.

With the by-pass in, the small 6.25 centimeter sphere gap across the windings, set for 15 kv, failed to spark over for any surge that could be applied up to the bushing flashover of 200 kv, but without the thyrite this gap operated with 22 kv applied.

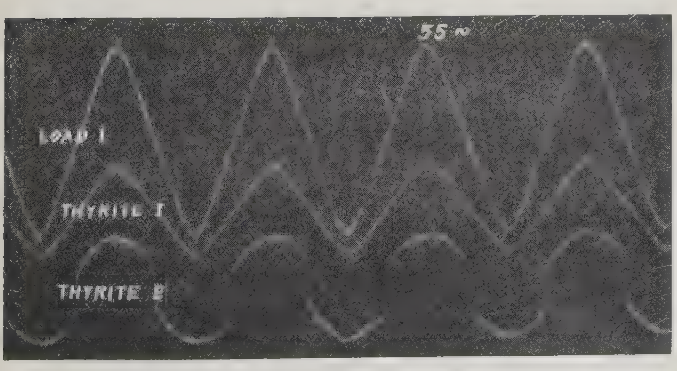


Fig. 10. Current and voltage wave shapes, with an open-circuit protector across the secondary of a standard 37 kv current transformer

Current transformer at 100 per cent rating

Tests on Open-Circuit Protector

Tests were made on a standard 37 kv current transformer to check the open-circuit protector. With no burden, with the protector disconnected, and with 100 per cent of rated primary sine-wave current, a peak voltage of 5,000 volts was measured across the secondary by a vacuum tube crest voltmeter. This voltage was considerably peaked, due to saturation, and had an effective value of 900 volts. With a protector consisting of 13 thyrite disks each 3 inches by $^1/_8$ inch, the open-circuit voltage was 96 volts effective, the wave form being quite rounded, as shown in the oscillogram of figure 10. This is an excellent check with the calculated results given previously.

The temperature rise of the thyrite at rated primary current was 90 degrees centigrade on continuous operation.

Figure 7 shows phase angle and ratio correction factors with and without the thyrite open-circuit protector. These curves were taken on a small 15 kv current transformer in order that the effect of the shunt might show up as much as possible. On larger transformers the effect of the thyrite is quite inappreciable and would not make so much difference on the correction factor curves. From these curves it is apparent that the accuracy of the current transformer has not been impaired by the addition of the shunt.

Reference

1. Shunt Resistors for Reactors—II, F. H. Kierstead and L. V. Bewley. Elec. Engg. (A.I.E.E. Trans.) v. 53, March 1934, p. 411–18.

Tentative Standards for Sound Level Meters

Tentative standards for sound level meters, for measurement of noise and other sounds, have been prepared by a committee of the American Standards Association. These tentative standards are published herein so that they may be put to use immediately. Comments and criticisms are invited.

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At the A.I.E.E. winter convention held in New York, N. Y., in January 1935 there was presented in a paper[1] on "Standardization of Noise Meters" a brief review of the status of standardization of noise meters and measurements and progress which had been made up to that time by the technical committee on noise meters and noise levels* of the American Standards Association. This technical committee has now completed the preparation of a set of tentative standards which has just been approved by the American Standards Association as "Tentative American Standard."

It was recognized by the sectional committee that any instrument suitable for measuring noise levels was also suitable for the measurement of other sounds so that the name of the instrument was changed to "sound level meter" and the committee which drafted the standard is now known as the "technical committee on sound levels and sound level meters."

In view of the interest now being taken by electrical engineers in general in the reduction of noise and in the measurement of noise levels, it seems desirable to supplement the earlier paper by publication in Electrical Engineering of the text of the "Tentative Standards for Sound Level Meters." Comments and suggestions based upon experience with meters conforming to the standards will be welcomed by the technical committee. In particular it is hoped that data which may be obtained bearing upon comparison of noise levels measured by such meters and ear balance loudness levels determined by standard methods will be brought to the attention of the committee. The committee will also be glad to receive new data relating to noise levels which will serve to supplement the information now available as to noise levels in various locations under different conditions.

These "Tentative Standards for Sound Level Meters" are based upon and are consistent with the "Proposed Tentative Standards for Noise Measurements" previously published.[2] Reference level is 10^{-16} watts per square centimeter in a free progresssive wave, reference frequency is 1,000 cycles per second, and a decibel scale is used. In addition, frequency response and dynamic characteristics of indicating instruments are specified. The text of the proposed standards follows.

Tentative Standards for Sound Level Meters

Foreword. The purpose of a set of standards for sound level meters is to bring about a condition such that, if a given noise of a general character is measured with any meter designed in accordance with the standards, the result will be substantially the same as that which would be obtained with any other similarly designed meter, and will approximate the loudness level which would be obtained by the more elaborate ear-balance method described in the proposed standards for noise measurement.[3]

Due to the complexities in the human hearing

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1. For all numbered references, see list at end of paper.

* The personnel of this committee is as follows:
R. G. McCurdy, Bell Telephone Laboratories, Inc., *chairman*
E. J. Abbott, Physicists Research Co.
T. G. Castner, Bell Telephone Laboratories, Inc.
W. F. Diehl, R.C.A. Victor Company, Inc.
E. E. Free, Consulting Engineeer, New York
C. R. Hanna, Westinghouse Electric and Mfg. Co.
H. E. Kent, Edison Electric Institute
H. W. Lamson, General Radio Company
H. B. Marvin, General Electric Company
H. S. Read, S. S. White Dental Mfg. Co.
S. J. Zand, Sperry Gyroscope Company
J. M. Barstow, Bell Telephone Laboratories, Inc., *secretary*

mechanism which cannot, at present, be adequately simulated in a sound level meter, it is expected that in many instances the approximations to loudness level will not be close, although differences in loudness level may be more closely approximated. The discrepancies involved can be determined more satisfactorily by comparison of meter readings and ear-balance loudness levels after a certain degree of uniformity has been attained among the meters in use by investigators in the field of sound measurements. It is, therefore, recommended that the standards for sound level meters proposed herein be accepted until further work and experience reveal advantages to be gained by revision.

Since the microphones used at present in sound level meters have directional characteristics, it will ordinarily be desirable, when sound measurements are made, to average the results of readings taken with the microphone turned in several different directions, including particularly those directions from which the sound appears to come. If this is done and the standards given below are met, differences between the results obtained with meters of different manufacture will be minimized.

It is recognized that, in special cases, certain non-standard characteristics may be desirable, and it is not intended that the proposed standards preclude the use of special characteristics for special problems.

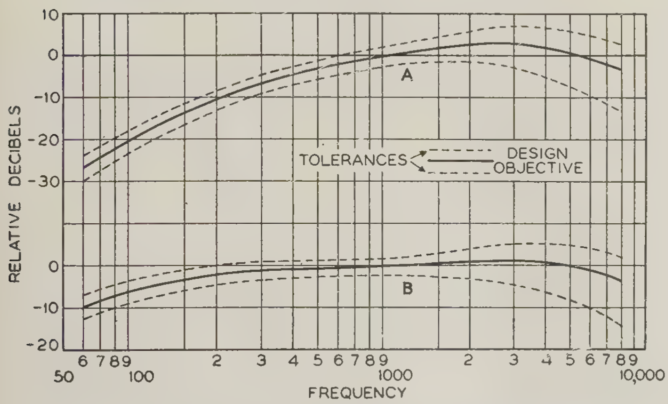

Fig. 1. Over-all free field frequency responses and tolerances for sound level meters

It is believed, however, that the proposed standards will aid in promoting uniformity in meter measurements of various types of sounds and will thus be of value in the sound measurements field.

Standards for Sound Level Meters

1. Scale. A sound level meter shall have a decibel scale. The quantity measured by sound level meters shall be referred to as "sound level"; *e. g.*, a sound level meter reading of 60 decibels shall be referred to as "60 decibel sound level," or "sound level of 60 decibels."

2. Frequency Response. The free field frequency response of a sound level meter shall be that shown in figure 1, curve *A*, provided only one such frequency response is available. If more than one frequency response is available, either the response shown in curve *B* of figure 1, or a flat response, or both, may be used in addition to the response shown in curve *A*. Curves *A* and *B* are the 40 and 70 decibel equal loudness contours, respectively, each modified by the differences between random and normal free-field thresholds.[4,5]

When reporting the results of sound level measurements the frequency response employed should always be given.

The tolerable deviations from the standard frequency responses at different frequencies are shown by the dashed curves on figure 1. The tolerances for a flat response would be the same as the tolerances for the *A* and *B* responses. To determine whether or not the tolerances are exceeded, the procedure outlined in appendix III is to be followed. The frequency response of a sound level meter shall lie within the tolerances for any setting of the gain controls with which the frequency response is intended to be used.

The free-field response at a given frequency shall be the average response for free waves at various angles of incidence up to 90 degrees from the normal, assuming all angles of incidence within this region equally probable. The method of averaging is described in appendix I.

The difference between the normal-incidence response and that for any other direction of incidence shall not exceed 5 decibels at any frequency up to 1,000 cycles and 20 decibels at any frequency between 1,000 and 3,000 cycles.

3. Reference Point. The reference point of the decibel scale incorporated in sound level meters shall be reference sound intensity (10^{-16} watts per square centimeter) at 1,000 cycles in a free progressive wave.

(Note: Some differences will usually exist between the standard frequency response and the response of an individual meter. In order that the primary calibration will result in a given noise of a general type producing substantially the same meter readings in meters whose frequency responses vary in different ways from the standard response, the procedure outlined in appendix III is to be used.)

4. Rule of Combination. The characteristic of the sound level meter shall be such that the meter will indicate the sum of the equivalent 1,000-cycle free wave intensities of the different single frequency components in the complex wave; that is, the power indicated for a complex wave shall be the sum of the powers which would be indicated for each of the single frequency components of the complex wave acting alone.

(Note: For most sound level meters, this rule will not be exactly followed for all types of input waves. Tolerable deviations from the rule of direct weighted power addition and tests to determine these deviations are given in appendix II.)

5. Dynamic Characteristic of Indicating Instrument. The dynamic characteristic of the indicating instrument forming a part of a sound level meter shall be such that the following over-all dynamic characteristics will be met by the meter:

(*a*) The deflection of the indicating instrument for a constant 1,000-cycle sinusoidal input to the sound level meter shall be equalled by the maximum deflection of the indicating instrument for an in-

put to the sound level meter consisting of a pulse of 1,000-cycle power which has the same magnitude as the constant input and a time of duration lying between 0.2 and 0.25 second.

(*b*) The deflection of the indicating instrument for a constant 1,000-cycle sinusoidal input to the sound level meter shall be exceeded by not more than 1.0 decibel by the maximum deflection of the indicating instrument obtained upon the sudden application of the constant input.

(*c*) The deflection of the indicating instrument for a constant 1,000-cycle sinusoidal input to the sound level meter shall be at least 1 decibel greater than the maximum deflection of the indicating instrument for an input to the sound level meter consisting of a 1,000-cycle pulse which has the same magnitude as the constant input and a time of duration of 0.1 second.

These characteristics should hold for any part of the scale of the indicating instrument.

In cases where it is not desirable to observe rapid fluctuations in level, a slow acting indicating instrument instead of the one described above, can be used for convenience to obtain an average result. On steady sounds the reading of this indicating instrument should be the same as that of the rapidly acting instrument.

Appendix I—Frequency Response of Sound Level Meters

When the microphone forming a part of a sound level meter responds differently to sound waves arriving with different angles of incidence, the reading of the meter will depend upon the directional characteristics of the sound waves at the point of measurement. In more or less diffuse sound fields, sound level meters having microphones with different directional properties will give different readings if they have been previously adjusted to give equal readings in the same normal incidence sound field.

These differences may be minimized by: (*a*) limiting the maximum difference between the normal-incidence response and that at any other angle; and (*b*) using a method of specifying the frequency response which takes into account the probable angles of incidence of the more important components of the sound. The maximum tolerable differences in response, and a method of specifying the over-all free-field response, are given in appendix II above; the following paragraphs give the details of the method of determining the response.

The over-all free-field response of a sound level meter as defined in appendix II may be computed from responses obtained to sound waves approaching the microphones at different angles within the specified region. The computation consists of averaging the microphone outputs for plane waves of a given frequency arriving successively from all directions within the given region, assuming that all such directions of arrival are equally probable. Since, in general, the variation of microphone output with angle of incidence is not easily expressible mathematically, it will be found practicable to use finite steps in the averaging process. An expression which has been found to give satisfactory results with condenser or dynamic microphones is

$$P = 0.034\,P_0 + 0.259\,P_{30} + 0.448\,P_{60} + 0.259\,P_{90} \qquad (1)$$

where

P = average power output of microphone
P_0 = power output from normal incidence wave
P_{30} = power output from wave 30 degrees to normal
P_{60} = power output from wave 60 degrees to normal
P_{90} = power output from wave 90 degrees to normal

The following is given as an example of the manner in which this expression is to be used. Measure the microphone response to free progressive waves at 0, 30, 60, and 90 degrees from normal incidence. Suppose that the following data are obtained:

Frequency	Angle	Measured Power Output for Free Field Input of 60 Decibels Above Reference Intensity
4,000 cycles	0	3 micro-microwatts
	30	1.9 micro-microwatts
	60	0.75 micro-microwatts
	90	0.38 micro-microwatts

Substituting in equation 1,

$$P = 0.034 \times 3 + 0.259 \times 1.9 + 0.448 \times 0.75 + 0.259 \times 0.38 = 1.03$$

Hence the average output power at this frequency for an input of 60 decibels above reference intensity is 1.03 micro-microwatts. (This $1.03/3 = 0.34$ of the output power for normal incidence, so that the over-all free-field response at 4,000 cycles, as defined in appendix II above is $10 \log 0.35 = -4.6$ decibels referred to the normal-incidence response.)

Equation 1 is derived as follows:

Assume that the microphone is symmetrical about an axis normal to the plane of the diaphragm, so that its output is constant for all directions of approach of sound waves which make an angle x with this axis. Make the approximation that the output is constant at a value P_0 for all values of x lying between 0 and 15 degrees, that it is constant at another value P_{30} for all values of x lying between 15 and 45 degrees, and so on.

Imagine a hemisphere, and a cone having its axis perpendicular to, and its vertex at the center of, the great circle on the hemisphere and having a vertex angle of 2×15 degrees. Since all directions of approach of the sound waves within the hemisphere are equally likely, the chance that a given sound wave will approach at some direction for which x lies between 0 and 15 degrees is the ratio of the area cut from the surface of the hemisphere by the cone to the total area of the hemisphere; this is found to be 0.034. Hence the contribution of the directions comprised within this cone to the output power is 0.034 P_0. Similarly the contribution of the direction lying between this cone and a cone with a vertex angle of 2×45 degrees is found to be 0.259 P_{30}; and so on. The total output is the sum of the contributions from all directions of incidence considered; this leads to equation 1.

If the assumption of symmetry of response about the axis normal to the plane of the diaphragm cannot be made, a number of measurements should be made, each representing the response for a certain

Table I—Example of Method of Comparing Individual and Standard Meter Responses

Frequency	Relative Acoustic Power in Decibels in 100-Cycle Bands of General Type of Noise	Standard Freq. Response (Curve A)	Sum	Corresponding Power
100	+ 9.7	−19	−9.3	0.12
200	+ 8.2	−11	−2.8	0.52
300	+ 6.9	− 7	−0.1	0.98
400	+ 5.7	− 5	+0.7	1.17
500	+ 4.5	− 3.5	+1.0	1.26
600	+ 3.4	− 2.5	+0.9	1.23
700	+ 2.3	− 1.7	+0.6	1.15
800	+ 1.5	− 1.0	+0.5	1.12
900	+ 0.7	− 0.4	+0.3	1.07
1,000	0	0	0	1.00
1,100	− 0.8	+ 0.5	−0.3	0.93
1,200	− 1.5	+ 1.0	−0.5	0.89
1,300	− 2.3	+ 1.2	−1.1	0.78
1,400	− 2.9	+ 1.4	−1.5	0.71
1,500	− 3.6	+ 1.6	−2.0	0.63
1,600	− 4.2	+ 1.9	−2.3	0.59
1,700	− 4.9	+ 2.0	−2.9	0.51
1,800	− 5.5	+ 2.1	−3.4	0.46
1,900	− 6.2	+ 2.3	−3.9	0.41
2,000	− 6.8	+ 2.5	−4.3	0.37
2,100	− 7.5	+ 2.7	−4.8	0.33
2,200	− 8.1	+ 2.9	−5.2	0.30
2,300	− 8.7	+ 3.0	−5.7	0.27
2,400	− 9.3	+ 3.0	−6.3	0.23
2,500	− 9.8	+ 3.1	−6.7	0.21
2,600	−10.3	+ 3.1	−7.2	0.19
2,700	−11	+ 3.1	−7.9	0.16
2,800	−11.5	+ 3.0	−8.5	0.14
2,900	−12	+ 3.0	−9	0.13
3,000	−12.5	+ 3.0	−9.5	0.11
	Sum of weighted powers			17.97

area of the hemisphere in front of the microphone. The average of the powers indicated by these readings, compared with the power indicated by the reading on the normal to the diaphragm will provide a means of determining the difference between the over-all free-field response as defined in appendix II and the normal free field response, providing all areas for which readings are taken are about equal in magnitude.

Appendix II—Tests for Power Addition

Make circuit arrangements so that 2 single frequencies with negligibly small harmonics may be introduced into the sound level meter input simultaneously and at the same time be controlled independently. The wave form of the frequencies should be purely sinusoidal and ideally they should be introduced acoustically, although if it is found preferable, because of distortion caused by loudspeaker or receiver characteristics, sinusoidal waves may be introduced electrically.

The frequencies must be in nonharmonic relation to each other and separated sufficiently so that the indicating instrument will not follow the beats. Choosing the frequencies above 800 cycles will aid in making the effects of oscillator harmonics negligibly small. Adjust the magnitude of each frequency so that it alone produces a mid-scale deflection of the indicating instrument. When adjusting one of the single frequencies, the impedance relations between this source, the meter input and the other source must be identical in every respect with the relations that exist when both sources are feeding energy into the meter input. As stated above, when adjusting one of the single frequencies the other must make no contribution to the meter deflection, though the impedance that it presents to the other frequency source and to the meter must be the same as before. When each frequency has been adjusted so that it alone produces a mid-scale deflection, both are put on together, and both are attenuated by the same amount until the mid-scale deflection is again obtained. This amount of attenuation should be 3 ± 0.5 decibels.

The experiment should be repeated at other points on the scale, including full scale.

Among the sounds of which measurements may frequently be desired will be steady peaked waves and sounds of such short duration that the meter will not follow them. For sounds such as these, the power addition property of the rectifier should extend somewhat beyond the region normally brought into play when a full-scale deflection is produced by a sine wave. Also, the amplifier should have some spare carrying capacity for these varieties of sound. Hence, it is necessary to make tests to insure that the amplifier and rectifier characteristics are such that power addition of components holds within certain limits for these types of sounds. To determine the adequacy of the meter in this regard, make the following test:

Insert a resistance network between the indicating instrument terminals and the points to which these are normally connected, so that the same resistance is presented to the rectifier as before, but so that, for a given power applied to the rectifier, less current flows through the indicating instrument than before. This resistance network should be such that its insertion causes a change in indicating instrument reading of about 7 or 8 decibels.

In the same manner as before make circuit arrangement so that 2 single frequencies, in nonharmonic relation to each other and separated sufficiently so that the indicating instrument will not follow the beats, may be introduced into the sound level meter input simultaneously and at the same time be controlled independently. Without the resistance network, adjust the magnitude of each frequency so that it alone produces a full-scale deflection of the indicating instrument. Insert the resistance network and increase the magnitude of each single frequency by 3 decibels. Note the indicating instrument deflection from either of the 2 single-frequency sources. (The deflection from each should be the same.) Put on both single frequencies simultaneously and attenuate both equally until the same deflection is again obtained. This amount of attenuation should be 3 ± 1 decibels.

Repeat the experiment except that after inserting the resistance network, increase the magnitude of each frequency by 6 instead of 3 decibels. Note the deflections from each single frequency (the deflections should be the same) and then put both on simultaneously attenuating both equally until the deflection obtained with either alone is again obtained. In this case the attenuation should be 3 ± 1.5 decibels.

These limits should be met for all positions of the calibrating and measuring gain controls.

Appendix III—Comparison of Individual and Standard Meter Responses

The purpose of comparing the response of a particular meter with the standard response is to make possible: (*a*) a determination of whether or not the response of the individual meter lies within the prescribed tolerances; and (*b*) a calibration of the individual meter such that on noise of a general character the reading given by the individual meter would be substantially the same as that which would be obtained from a meter having the standard response. The method consists of computing for an average noise the weighted power outputs of, first, a meter having the standard response and, second, the particular meter in question. These outputs may be made equal by suitably adjusting the calibration of the particular meter in question. After making this adjustment in the individual meter, its response would be compared to the standard response in order to determine whether or not the particular response to various single frequencies falls within the tolerances. The example shown in table I gives the details of the method of comparison and in addition gives the average relative magnitudes (in decibels) of acoustic energy in 100 cycle bands obtained from analyses of noises of a general character. This is the energy-frequency distribution of noise which is to be used in computations comparing the readings of a standard meter and an individual meter for purposes of calibrating the individual meter. To make this comparison, the only additional information necessary is the single-frequency response characteristic of the individual meter.

Since it is apparent that the total power would not be greatly affected by frequencies above 3,000 cycles, the summation is purposely stopped at this frequency.

By going through this same process for the individual meter response (substituting the individual meter response, plotted so that it passes through 0 decibels at 1,000 cycles, for the "standard frequency response, curve *A*"), another value for "sum of weighted powers" will be obtained. If this value is the same as that obtained from the computations using the standard frequency response, then the individual meter should be calibrated so as to give a reading of 0 for reference sound intensity at 1,000 cycles. If the sum of the weighted powers for the individual meter is different from that for the standard meter, the individual meter should be calibrated so that reference intensity at 1,000 cycles produces a reading of x decibels, where

$$x = 10 \log_{10} \frac{\text{sum of weighted powers, standard meter}}{\text{sum of weighted powers, meter in question}}.$$

To determine whether the individual meter response falls within the tolerances, the individual meter response, shifted by x decibels, may be superposed on the standard response. In this position, relative to standard response, the individual meter response should fall within the dashed lines given on figure 1. The direction of the x decibel shift is as follows: If the sum of the weighted powers for the meter in question is smaller than the sum of the weighted powers for the standard meter, the x decibel shift should be upward when plotted on figure 1.

A similar process should be used to determine if the *B* weighting in a particular meter does not depart from the standard *B* weighting by more than the tolerable amounts, and to calibrate the meter for use with the *B* weighting.

References

1. Standardization of Noise Meters, R. G. McCurdy. Elec. Engg. (A.I.E.E. Trans.) v. 54, Jan. 1935, pages 14–15.

2. Proposed Standards for Noise Measurements, Harvey Fletcher. Elec. Engg., v. 52, Nov. 1933, p. 744–6.

3. Proposed American Tentative Standards for Noise Measurements. Report Z24/20, prepared by A.S.A. Sectional Committee on Acoustical Measurements and Terminology, subcommittee on noise measurements.

4. Proposed Standards for Noise Measurement. *Jl.* of the Acoustical Soc. of Am., v. 5, No. 2, Oct. 1933, p. 110 (fig. 1).

5. On Minimum Audible Sound Fields, L. J. Sivian and S. D. White. *Jl.* of the Acoustical Soc. of Am., v. 4, No. 4, Apr. 1933, p. 288–321.

Measuring Equipment for Oil Power Factor

Equipment for power factor measurements of insulating oils, especially designed to insure accuracy of result and to offset difficulties commonly encountered, is described in this paper together with an operating technique that has been found to produce highly satisfactory results. Extraneous factors likely to influence the accuracy of results also are mentioned.

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THAT certain electrical measurements are more sensitive as criteria of the deterioration of such complex liquid dielectrics as petroleum oils than most chemical tests, is generally recognized. Much of the advantage gained in sensitivity is lost, however, because most of the electrical measurements are influenced by somewhat nebulous factors which have little bearing upon the inherent nature of the oil. This is particularly true of the d-c (1 minute) resistivity. The variations in this test, using carefully designed equipment under fixed conditions, may not be large when successive measurements are carried out in one laboratory, but interlaboratory comparisons on the same oil rarely agree. As an example of the magnitude of the variations which may be encountered, a recent A.S.T.M. co-operative test on a series of 8 cable oils may be cited in which the Socony-Vacuum general laboratories participated. These oils ranged in resistivity from 10^{12} to 10^{15} ohms per centimeter cube. In the worst case, the oil with the highest resistivity varied by a factor of 12 as determined by the 3 co-operating laboratories. Variations by factors of 2 and 3 were common. Only with the oil of lowest resistivity was there reasonable agreement. The exact cause for this large lack of agreement is difficult to determine, but apparently differences in apparatus, and particularly in the resistivity cells used, may have been responsible for most of it. Furthermore, better agreement appears hopeless unless the cell, and perhaps other equipment used, is standardized.

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements. Manuscript submitted Nov. 30, 1935; released for publication Jan. 4, 1936. Based upon a presentation before the meeting of the National Research Council's committee on electrical insulation, Pittsfield, Mass., Oct. 10–17, 1935.

The author wishes to express his appreciation to the Socony-Vacuum Oil Company, Inc., for permission to publish this work, and to acknowledge the assistance of his associates B. W. Story, W. G. Horsch, and T. M. Gunn.

This situation with regard to resistivity has been partially responsible for this study of power factor made in an effort to determine whether the test is more reliable than the resistivity test. This aim has not been realized as yet, for interlaboratory comparisons have not yet been carried out to show the exact state of affairs. It is hoped that this can be done in the near future. Hence, this paper will be restricted to: (1) the description of carefully designed equipment for measuring the power factor of insulating oils; (2) the description of a technique which has been found to be satisfactory; and (3) pointing out some of the factors which may influence the results. The bridge and associated apparatus were designed keeping in mind simplicity and speed of operation without sacrificing too much of the accuracy and sensitivity necessary for measuring the low power factors found in good insulating oils.

Summary

Results obtained with the apparatus and operating technique covered in this paper may be summarized by mentioning the following more important points:

1. With the bridge and associated apparatus described power factors as low as 5 by 10^{-6} can be measured with reasonable accuracy. This represents a sensitivity sufficient for studying, in the temperature range from 20 to 100 degrees centigrade, the best oils available.
2. The power factor-temperature curve is approximately a straight line on a semilog plot for a wide variety of oils investigated in the limited temperature range from 20 to 100 degrees centigrade. This was shown to be in qualitative agreement with the conduction theory. It can be used as a check on the performance of bridge and associated apparatus.
3. Moisture affects the shape of the power factor-temperature curve, usually causing it to become concave upward on a semilog plot.
4. Unless an oil is known to be dry, vacuum treatment before measuring the power factor will insure against erratic results, which the presence of moisture may cause.
5. A closed aging vessel leads to more consistent results in determining the stability of an oil on aging at elevated temperatures than can be obtained by using an open vessel.

Description of Bridge Circuit

A schematic diagram of the modified form of Schering bridge is shown in figure 1. Some innovations were made in the bridges described by Kouwenhoven and Banos[1] and Balsbaugh, Kenney, and Herzenberg.[2] The heavy solid lines in the illustration indicate the active portions of the bridge, the light solid lines the shielding, and the dashed lines the screened cage.

An idea of the physical layout of the bridge apparatus may be obtained from figure 2. The main bridge cage is 6 feet square and contains a U-shaped table upon which all of the apparatus of the low voltage bridge arms is mounted. Some of this apparatus and the operator's stool may be seen through the

door in the front of the cage. The variable high voltage air capacitor may be seen at the top with 2 sides of the metal housing temporarily removed. The housing is not necessary for shielding, but is used for safety and to prevent dust from collecting on the plates. At the right in the smaller cage may be seen the thermostatically controlled oil bath in which the cell containing the oil is placed. At the top and to the left is the cable from the high voltage transformer which feeds the bridge.

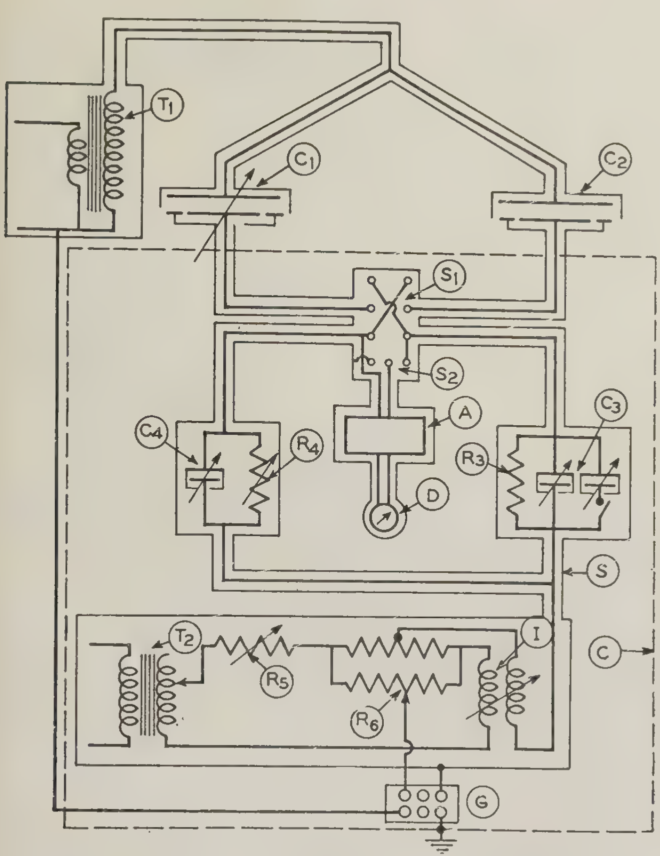


Fig. 1. Schematic diagram of Schering bridge as modified

C_1—Standard high voltage capacitor variable from 75 to 400 micromicrofarads at 5,000 volts
C_2—Power factor cell for oil
T_1—110 to 11,000 volt supply transformer fed by ordinary 60 cycle power
C_3—Consists of 2 variable precision capacitors, one permanently connected ranging from 50 to 1,300 micromicrofarad and the other (mica dielectric) ranging from 1,000 micromicofarad to 0.110 microfarad which is connected into the circuit only when high power factors are to be measured
R_3—5,000 ohm fixed resistor
C_4—50 to 1,500 micromicrofarad variable precision capacitor
R_4—11,111.1 ohm resistor variable in 0.01 ohm steps
D—Leeds & Northrup 60 cycle vibration galvanometer
A—Leeds & Northrup 60 cycle amplifier
S_1—Double-pole double-throw switch used when bridge is operated at 1-to-1 ratio for eliminating effect of unbalanced capacitances in low voltage arms in measuring low power factors
S_2—Single-pole double-throw switch used in adjusting detector potential to the same value as that of grounded shields
T_2—110 to 15, 10, and 5 volt transformer which is energized from the same source as that of T_1 and which in turn energizes the modified Wagner ground circuit
R_5—1,000 ohm decade resistor
R_6—500 ohm circular slide wire resistor
I—Variable mutual inductor
S—Grounded shielding
G—Ground plate
C—Screen wire cage

Special Features of the Bridge

The high voltage variable air capacitor is made of monel metal plates to eliminate possible power loss due to oxide formation on the surface. This possible loss in air capacitors was first pointed out by Balsbaugh and Moon.[3] The plates are $^1/_8$ inch in thickness and are backed by a simple angle iron frame to obtain the necessary stiffness. The high voltage plate, which is 4 ft square, is suspended by 4 bus bar insulators as shown in figure 2. The low voltage plate, with its 6-inch-wide guard ring and its 3-foot-square active portion, is supported at 3 points, 2 of which are visible in figure 2. These supports consist of threaded rods which screw into the frame

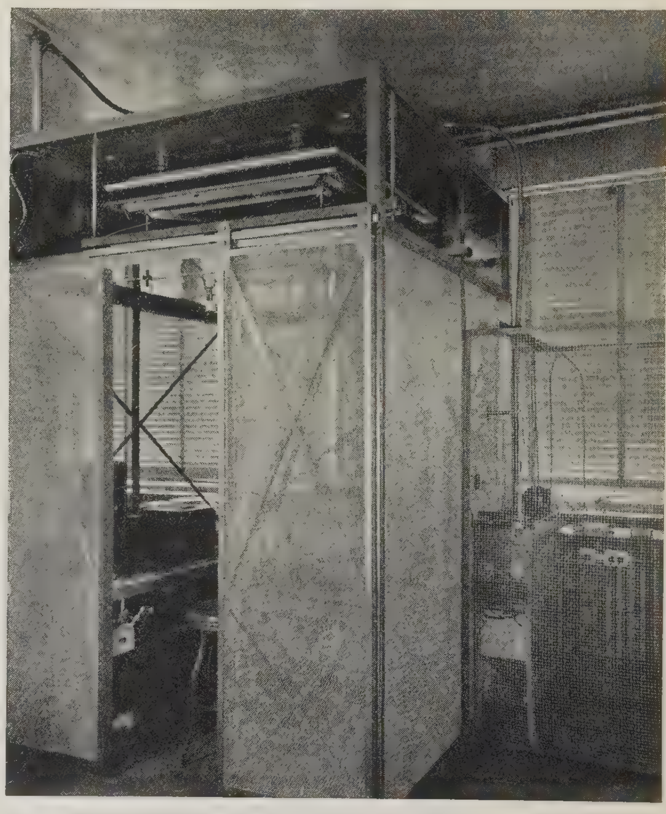


Fig. 2. Physical arrangement of bridge apparatus

beneath the capacitor and which are tied together by means of sprocket wheels and chain. The third support terminates in a crank wheel placed within easy reach of the operator. To provide a fine adjustment of the spacing the third support is fitted with a sleeve having on the inside threads of a pitch differing slightly from those on the outside; this sleeve also terminates in a crank wheel directly over the first. Thus the air capacitor always can be adjusted to the same capacitance as that of the cell containing the oil, first by making a coarse adjustment with one crank wheel and then a fine adjustment with the other, the latter causing a very

slight tilting of the plate. This adjustment can be made so close to the 1-to-1 ratio that R_4 (figure 1), which is used to obtain the complete balance, has to be changed less than 1 part in 10,000 from equality with R_3.

The circuit shown in the lower part of figure 1 is essentially a Wagner ground because, among other things, its function is to bring the detector to ground potential. The principal difference from the usual Wagner ground is that instead of applying the full voltage across this circuit only a small fraction of it is applied through the use of the low voltage transformer T_2. A slightly different form of this circuit was described by Kouwenhoven, Dike, and McCurley.[4] Besides simplicity of construction and use, its advantages over earlier schemes are: (1) all guard rings and shielding can be grounded solidly, and, more important (2) the detector and amplifier can be operated at ground potential, thus eliminating much amplifier trouble.

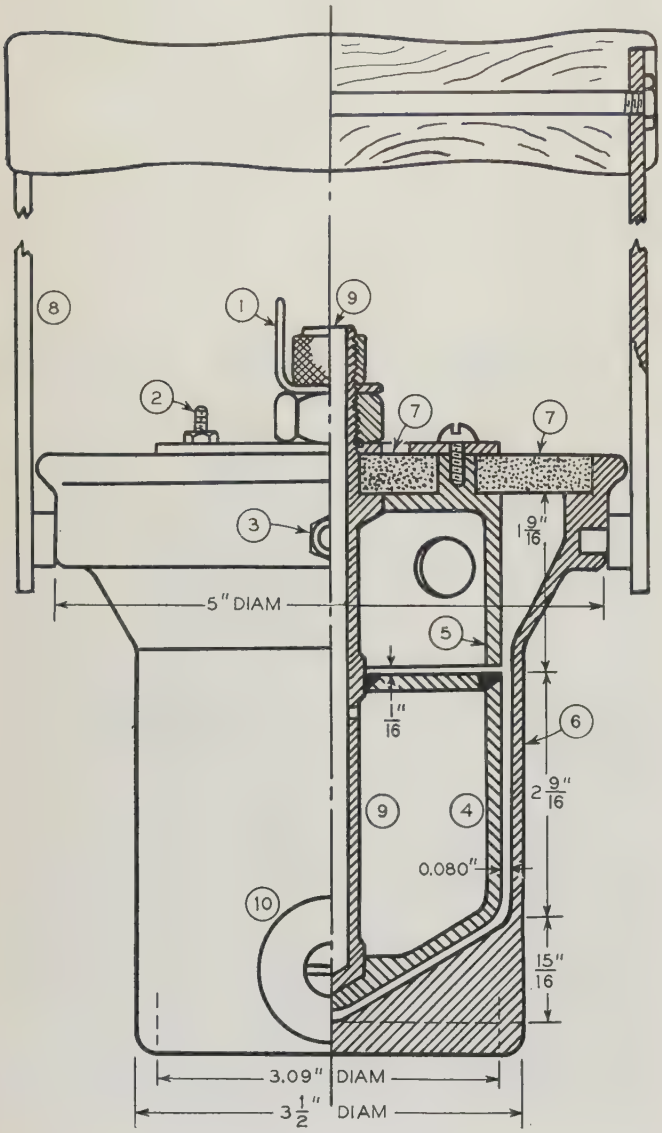


Fig. 3. Half sectional view of power factor cell

1—Low voltage lead
2—Guard ring lead
3—High voltage lead
4—Low voltage or active electrode
5—Guard ring
6—High voltage electrode
7—Translucent quartz rings
8—Detachable handle
9—Thermometer well
10—Bakelite knob for emptying cell

The detector circuit consists of a Leeds & Northrup 60 cycle amplifier A and a Leeds & Northrup 60 cycle vibration galvanometer D shown diagrammatically in figure 1. The amplifier contains 2 stages of amplification which are resistance-capacitance coupled, and an output transformer which is triply shielded against magnetic and electrostatic disturbances. The galvanometer is shunted across a 5,000 ohm grid leak in the plate circuit of the second and last stage. A potentiometric arrangement is provided for adjusting the amplification to any convenient value. The galvanometer has a resistance of 700 ohms and a current sensitivity of 0.025 microampere. The relatively low resistance of the 5,000 ohm grid leak of the amplifier, across which the galvanometer is shunted, broadens the otherwise sharp frequency-sensitivity characteristic of the galvanometer. This eliminates troublesome fluctuations in sensitivity that otherwise would result from the small variations in frequency of an ordinary power supply. In doing this, however, some over-all sensitivity is sacrificed.

The derivation of the bridge equation will not be given here for it has been reported several times in the literature. However, certain special cases which apply to this circuit will be discussed. The complete equation for tan δ, which is very nearly equal to the power factor for values less than 0.1, is

$$\tan \delta = \frac{\omega[(C_3R_3 - C_4R_4) - (C_3'R_3' - C_4'R_4')]}{2}$$

where ω is 2π times the frequency; C_3, C_4, R_3, and R_4 are the readings at balance of the corresponding capacitors and resistors shown in figure 1 when the reversing switch S_1 is in one position; the primed letters indicate the readings when the reversing switch is in the other position. Operation at 1-to-1 ratio simplifies this equation because in balancing the bridge R_3 never is allowed to depart from equality with R_4 by more than 1 part in 10,000, and the same is true of the primed values. Therefore, to more than sufficient accuracy, $R_3 = R_4 = R_3' = R_4' = R$. A further simplification can be effected in measuring low power factors (below 10^{-3}) by allowing C_4 to remain fixed at the midpoint of its scale during the whole balancing procedure. This makes $C_4 = C_4'$ and the equation for this case becomes

$$\tan \delta = \frac{\omega R(C_3 - C_3')}{2}$$

Just as the use of the reversing switch S_1 eliminated the fixed capacitance C_4 from the equation, it also will eliminate the fixed unbalanced distributed capacitances of R_3 and R_4 and their leads to the modified Wagner ground circuit. In measuring high power factors (above 10^{-3}), however, the reversing switch need not be used. In this case the unbalanced distributed capacitances are negligibly small compared

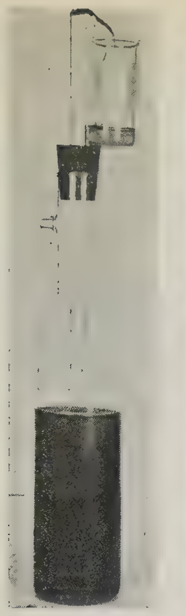


Fig. 4. Closed glass cell for aging oil

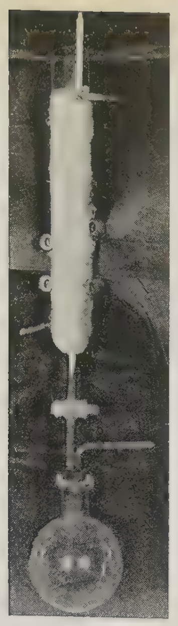


Fig. 5. Apparatus for dehydrating oil

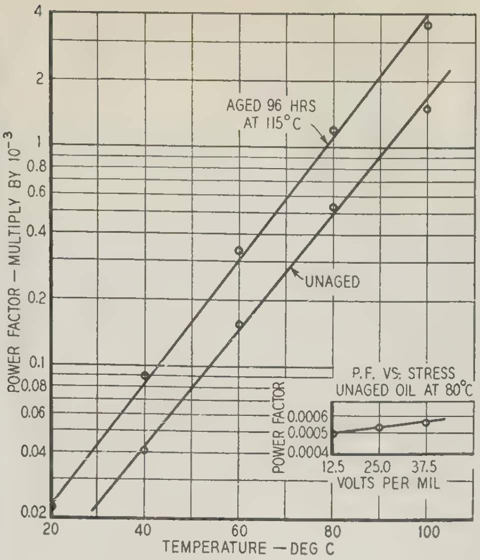


Fig. 6. Example of results obtainable with apparatus and procedure described; oil for solid core cables

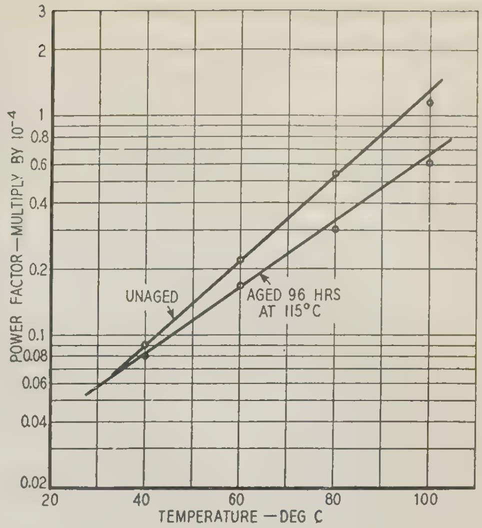


Fig. 7. Example of results obtainable with apparatus and procedure described; oil for oil filled cables

with the value of C_3 necessary to obtain a balance. Thus, for high power factors the equation becomes

$$\tan \delta = \omega R(C_3 - C_4)$$

To obtain this balance, C_4 is set at the low end of its scale and the second capacitor shown in the C_3 arm of the bridge is connected into the circuit if necessary. The unbalanced distributed capacitance for this bridge is less than 10 micromicrofarads.

Description of Power Factor Cell

In measurements on dielectric liquids, the cell is perhaps the most important element of the bridge. It has been the custom to place the blame for unsatisfactory results on the bridge, but with the present state of the measurements art this should no longer be true. In case of trouble, the cell should be accorded most of the suspicion. Many designs of cells have been proposed, some of these however, for one reason or another, are unsatisfactory for measurements on oils. Experience shows that a carefully constructed cell will save much time and worry. In the design shown in figure 3, all of the parts coming into contact with oil were turned from monel metal stock. An earlier form of this cell which can be used only for resistivity was described by Horsch and Berberich.[5]

It has been found that monel and nickel have considerably less catalytic effect in the oxidation of the oil than have either brass or copper. Inasmuch as it was desired to avoid plating with nickel, solid monel was used. Another laboratory, however, has duplicated this cell using nickel plated brass as the electrode material, and bakelite instead of the translucent quartz as interelectrode insulation, and very satisfactory performance has been reported. This modification lowered the cost of the cell. The danger of using plated electrodes is that the plating may be damaged with time, thus exposing the undesirable base metal. This whole question of the effect of the metals upon the measured power factor bears further investigation.

The cell can be placed either in an oil bath or air bath for heating. If an oil bath is used, a water cooling coil will aid considerably in varying the temperature over a range. The temperature of the cell is measured by having one thermometer in the well provided in the center of the cell and another in the bath. The average of thermometer readings gives very nearly the average temperature of the oil. Approximately 50 cubic centimeters of oil are necessary to fill the active portion of the cell and 50 cubic centimeters more are required to fill the guard ring portion to a height of 1 inch. The 80 mil layer can be stressed up to 5,000 volts or, 62.5 volts per mil, and perhaps higher. The capacitance in air is 85.7 micromicrofarads, and approximately 200 micromicrofarads when filled with oil, the latter value depending on the dielectric constant of the oil. The cell has the following advantages:

1. It can be cleaned quickly when at a temperature of 80 degrees centrigrade by giving it 2 washings of benzol followed by a washing of a more volatile solvent such as petroleum ether.

2. No dismantling is required for cleaning, except for lifting out the inner electrode assembly.

3. A smooth surface is maintained, allowing no trapping of oil.

4. No solid insulation in the oil which may absorb oil and contaminate subsequent samples.

5. No solid insulation in the field.

6. No appreciable catalytic effect of the metal on all except very unstable oils.

Technique of Making Measurements

The usual procedure in studying an oil is not only to measure the power factor over a range of temperature, but also to determine the power factor stability on aging the oil at elevated temperatures. To pre-

vent possible contamination of the various samples of oil placed in an aging bath by the intermingling of vapors, a special closed vessel of heat resisting glass is used. That such contamination is possible can be proved easily by aging a certain oil alone and then repeating the test by placing alongside it other oils of poorer aging characteristics. The power factor on the aged oil in the latter case usually is found to be considerably higher than in the former case. Contaminated laboratory air also may often be reponsible for erratic results.

Referring to figure 4, showing the aging vessel, purified and dried air is passed into the vessel through the side arm in the neck. The air then passes over the surface of the oil and bubbles out through the oil seal at the top of the vessel. The air is purified by passing it through sulphuric acid and soda lime. A manifold, in which the pressure is maintained at a constant value, and calibrated capillary tubes are used to distribute the air to each of a number of vessels in the bath at the rate of 2 liters per hour. Except for oils of extremely poor stability, small variations in the rate have no effect when the rate is this high. More consistent results have been obtained with this procedure than with the so-called "open beaker test" where free intermingling of vapors and contamination by laboratory air are possible.

Moisture is one of the most insidious enemies of all insulation. Moisture also can cause much trouble when reliable power factor measurements on oil are required. An oil standing open to air for any length of time will absorb moisture which, depending upon the amount and temperature, may either be dissolved or distributed in droplets of colloidal dimensions. It has been found, as will be discussed later, that, unless it is certain that an oil contains no moisture, some treatment must be given it if reliable power factor measurements are to be obtained. This treatment can be accomplished by the use of the very simple apparatus shown in figure 5. The apparatus consists of (1) a glass tube wound with a heater, fitted with a stopcock and a capillary nozzle, and (2) a round bottom flask into which the nozzle is fitted and to which a vacuum is applied. The treatment consists of heating the oil to 80 or 90 degrees centigrade for a short time and then spraying it very slowly into a vacuum of at least 5 millimeters of mercury. Before transferring the oil for power factor measurement, the cell should be heated to 100 degrees centigrade, or slightly above, so that no moisture will remain condensed on the electrode surfaces.

Examples of the results obtainable with the apparatus and procedure described herein are given in figures 6 and 7. The data of figure 6 apply to an oil of the type commonly used in solid core cables and having a viscosity of 130 Saybolt seconds at 210 degrees fahrenheit, and those of figure 7 to an oil of the type commonly used in oil filled cables and having a viscosity of 100 Saybolt seconds at 100 degrees fahrenheit. Both these oils have high power factor stability. In figure 7 the abnormal change in power factor with aging shown by this particular oil can be explained by assuming that the oil inherently changed little during the aging period, and that some volatile impurities were driven off during the process of aging at an elevated temperature. Attention is called to the extremely low power factors measurable with this apparatus.

It should be noted that the curves are practically straight lines in a semilog plot over the limited temperature range from 20 to 100 degrees centigrade. A wide variety of oils all gave the same type of curve. This is what might be expected from the viscosity-temperature relationship. If the reciprocal of the absolute viscosity is plotted against temperature on a semilog plot the curve obtained is slightly convex upward, but reasonably near a straight line in the range from 20 to 100 degrees. Assuming that, under fixed conditions of voltage stress and concentration of ions, the mobility of the ions entering into the conduction phenomenon varies inversely as the viscosity, the power factor curve should follow the reciprocal-viscosity curve. In figure 6 there is evidence that the power factor-temperature curve would have been slightly convex upward if the curve had been drawn through all the points. Usually the nearest straight line will suffice. Whitehead[6] has found that the product of the short-time d-c conductivity and the viscosity for a given oil is essentially independent of the temperature within this range. This is entirely in agreement with the writer's findings. Thus, this relationship between power factor and temperature provides a simple and valuable method for checking the performance of the bridge and associated apparatus.

When moisture is present in the oil there is generally a marked departure from the relationship just discussed, and instead of the curve being convex upward it is concave upward. In some cases moist oils showed actual power factor minimums; that is, the power factor increased as the temperature was decreased below 40 degrees centigrade. This can be explained by assuming that, as the temperature is decreased, more and more of the dissolved moisture separates out from the oil which in some not yet completely understood way causes a progressive increase in power factor. After such an oil was given the dehydrating treatment described, the straight line relationship always resulted. Inasmuch as a power factor-temperature curve for a moist oil could not be reproduced satisfactorily, no representative curve is included in this paper. However, this serves to show that moisture can be responsible for erratic results in power factor measurements on insulating oils.

References

1. A High Sensitivity Power Factor Bridge, W. B. Kouwenhoven and A. Banos, Jr. A.I.E.E. Trans., v. 51, March 1932, p. 202–10.

2. The M.I.T. Power Factor Bridge and Oil Cell, J. C. Balsbaugh, N. D. Kenney, and Alfred Herzenberg. Elec. Engg., v. 54, March 1935, p. 272–9.

3. A Bridge for Precision Power Factor Measurements on Small Oil Samples, J. C. Balsbaugh and P. H. Moon. A.I.E.E. Trans., v. 52, June 1933, p. 528–35.

4. A Modified Schering Bridge, W. B. Kouwenhoven, P. H. Dike and J. B. McCurley. A.S.T.M. *Proc.*, v. 35, pt. 3, 1935, p. 727–33.

5. A Cell for Routine Electrical Measurements on Insulating Oils, W. G. Horsch and L. J. Berberich. *Rev. Sci. Instr.*, v. 5, 1934, p. 194–6.

6. Dielectric Losses in Impregnated Paper, J. B. Whitehead. A.I.E.E. Trans., v. 52, June 1933, p. 667–81.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 27 pages appear the final authors' closures of papers presented at the 1935 A.I.E.E. summer convention, Ithaca, N. Y., June 24–28; discussion of papers presented at 2 sessions of the 1935 Pacific Coast convention, Seattle, Wash., August 27–30; and discussion of papers presented at the 1935 Great Lakes District meeting, West Lafayette, Ind., October 24–25. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Circuit Breakers for Boulder Dam Line

Author's closing discussion of a paper published in the April 1935 issue, pages 366–72, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935. Other discussion of this paper was published in the February 1936 issue, pages 196–7.

D. C. Prince: Both Joseph Slepian and W. M. Leeds, by their discussion, bring out one very interesting thought. We electrical engineers have become accustomed to thinking in very exact terms. Ohm's law amplified by Faraday and Maxwell can be applied with a degree of precision entirely unknown in most other engineering work. The accurate stress analysis of the civil engineer is multiplied by factors of safety given in integral numbers. That is, he does not add a 10 per cent margin of safety but makes his structure 2 or 3 times as strong as theoretically necessary, to account for secondary stresses.

The hydraulic engineer is in an even more difficult position. All but the simplest of his flow relations yield equations almost impossible of exact solution. The oil circuit breaker is a composite electrical and hydraulic problem, and as such it must be looked at through the eyes of the hydraulic engineer. Bernouilli's law is simple, because it brushes aside all the complicating factors that worry Slepian. It is our problem to find whether, for practical purposes, we can do likewise. Let us consider these various disturbing factors in the order in which he has raised them:

Current magnitude is important only as it alters the oil velocity. With sufficient port area, no change in oil velocity with current is observable.

Arc length is transverse to principal direction of oil flow and so is unimportant.

Voltage of circuit may cause a breakdown along a new path, before contacts are sufficiently separated. This only postpones clearing until the contacts are sufficiently separated but does not affect the equation.

Location of oil velocity cancels out when taken together with the impulse strength of the oil. If we assume the effective velocity less and the dielectric strength greater, we get the same over-all coefficient, which is the end sought.

Pressure—velocity relations, according to Bernouilli's law, are met because the oil velocity in the tube is so low that the velocity head is only about 0.15 per cent while the free surface is close above the end of the port. The oil above the port is blown away while the other motions are getting started.

Transient effects on Bernouilli's law are negligible. Calculations and test show that the oil is up to full speed in less than a quarter of a cycle.

Viscosity effect and fluid friction are negligible because at the velocity encountered almost all the energy is used in acceleration. The passages are short. Tests at subzero temperatures show no slowing down.

Figure 10 is a composite of several tests and so does not correspond exactly with figure 9, which, of course, is a single test.

As stated in the beginning, the hydraulic relationships do not have the precision of Ohm's law. A circuit breaker of the highest capacity, highest voltage, and shortest operating time has been designed quantitatively, out of whole cloth. There was nothing that could be expanded slightly to bring it into being. Yet it worked; it worked the first time, and it worked as its designers said it should. In spite of academic criticism, the oil blast theory stands upon the sound practical base. It works.

Oil Circuit Breaker and Voltage Recovery Tests

Authors' closing discussion of a paper published in the February 1935 issue, pages 170–8, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935. Other discussion of this paper was published in the February 1936 issue, pages 193–4.

E. J. Poitras, H. P. Kuehni, and W. F. Skeats: The authors agree with B. E. Hagy that it is unfortunate that arrangements could not be made whereby short-circuit currents substantially equal to the breaker rating could be obtained. However, on the basis of the characteristics of oil blast breakers as established by a large number of tests, they feel confident that, other things being equal, the presence of higher currents would have had very little effect, and that favorable, upon the arc lengths. The only point left in question is the ability of the parts to stand up mechanically, and this has been checked by tests made in the manufacturers' laboratory, where considerably higher currents were interrupted at a reduced voltage.

The authors agree also with D. C. Prince that extreme accuracy in the determination of voltage recovery rates is not required.

The Determination of Circuit Recovery Rates

Author's closing discussion of a paper published in the May 1935 issue, pages 530–9, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935. Other discussion of this paper was published in the February 1936 issue, pages 191–3.

E. W. Boehne: In reply to R. C. Van Sickle's question concerning the use of "recovery impedance" as a criterion for comparing one circuit with another independent of the current which is being interrupted, I feel that further explanation is in order.

The recognized criterion for arc extinction is the rate of rise of recovery voltage. This has been shown in the paper to be numerically the product of 4 terms, the 2 most important of which are the current interrupted and the recovery impedance of the circuit. Both are indispensable in forming the recovery rate. Recovery impedance is the static component of recovery rate contributed by the physical constants and their arrangement in the circuit. The current which is being interrupted is the dynamic component of the recovery rate. Recovery impedance merely describes the hardness or toughness of the circuit at the breaker, against which the mass (inductance) of the complete circuit is being hurled at a velocity (current) to produce the sudden appearance of forces (voltages) at the terminals of the breaker. The addition of capacitance (spring properties) at the terminals of the breaker will greatly ease the shock of these electrical impacts. The current is essentially independent of the recovery impedance inasmuch as the current *may* be limited by circuit constants which affect

the recovery impedance in only a small way. The capacitances of the circuit have no part in determining the current but are indispensable in determining the recovery impedance.

The above division of recovery rates into the various components of which they are composed has had many other advantages apart from making the calculation of recovery rates easier. Primarily it has afforded a clearer concept, in understandable terms, of what goes together to form a high recovery rate. Secondly, in analyzing a high recovery rate the various components can be studied separately to see what can be done. They describe tangible circuit characteristics. In this connection I repeat that the recovery impedance component, being available, can be compared with the recovery impedances of other circuits and is the accurate criterion for comparing one circuit with another, independent of the current which is being interrupted. In one survey made for a utility network, recovery impedances ranging from 150 ohms to 13,000 ohms were found. The highest recovery rate, however, was associated with a recovery impedance of about 9,000 ohms, merely because the product of the recovery impedance and the current interrupted was maximum for that case. Thirdly, it will be found that simple switching operations near the breaker can materially alter the recovery impedance without affecting the current in any way. Here the division of recovery rate into its various components is a decided help not only in computation, but in visualizing just what contributed to the change in recovery rate for the various conditions. In many cases where the recovery impedance is determined by a single frequency circuit close to the breaker, it will be found that the current may vary over a wide range by reason of other reactances in the circuit. Here the single calculation of the recovery impedance will suffice for a number of recovery rate calculations.

With a little study of figure 7 of the paper, together with a dozen or so practical calculations, one can learn to classify circuits in the order of their recovery impedance by inspection. Such a recovery impedance survey, together with a knowledge of the short-circuit currents as determined from a short-circuit board study, gives the system engineer the necessary data to tabulate the probable recovery rates he may expect for various circuit conditions. When such a survey is compared with the record of of breaker performances the results are usually gratifying enough to warrant the effort.

Joseph Slepian reports that his observations show that the circuit recovery time is of more importance than the maximum recovery rate. If such were the case, in cathode ray oscillograph studies interruptions would have been observed which would restrike at intervals of several hundred microseconds. No such conditions have been observed. It is significant, however, that regardless of how straight edges may be applied to the complete recovery characteristic in attempting to define a severity factor, the recovery voltage oscillations themselves have not changed. By means of the tables and curves contained in the paper, the user may determine quickly and accurately for the circuit he has chosen the 2 major frequencies and their corresponding amplitudes. How he uses this information is a matter of his own experience. It has been found by extensive field and laboratory investigations that the steepest tangent which can be drawn to the recovery voltage characteristic, provide the point of tangency is at a voltage above the root mean square value of rated voltage, determines a factor which is consistent with the performance of the breaker when operating close to its rated capacity. This factor is termed the recovery rate and is measured in volts per microsecond. Its calculation and interpretation have been simplified by the introduction of the recovery impedance as described in the paper.

In early plain break circuit breakers, the arc lengths were inherently long as it required the additional arc resistance and the formation of a leakage path following interruption, both of which acting together held the recovery rate to a value at which the circuit could eventually be cleared. As more modern interrupting breakers were developed which placed fresh uncarbonized oil in the arc path, it became clear that the breakers were encountering and overcoming higher rates of rise and by so doing were interrupting in a fraction of the time required by plain break breakers. This evolution has been steady until with the development of piston operated oil blast breakers ["Circuit Breakers for Boulder Dam Line," D. C. Prince, Elec. Engg. (A.I.E.E. Trans.) v. 54, April 1935, p. 366–72] the circuit is cleared at the end of the first full half cycle of arc. Here the breaker has overcome the maximum recovery rate attainable, and in many respects approaches the conditions of an ideal breaker. The significant feature of the interrupting tests made with this breaker is that the data, when correlated with the recovery rate obtained for each test, show a most striking correlation in support of the principles upon which it was designed. If circuit recovery time were the predominate factor, it is hard to see how the observed correlation with recovery rate could exist.

In present day design and application of breakers, attention is being paid to overcoming the maximum field recovery rates. Probably the most striking field observations of the effect of recovery rates can still be observed in connection with the performance of plain break breakers. With high recovery rates the arc lengths are long, the arcing times are long, and hence the oil deterioration is rapid. As a result oil carbonization versus breaker short circuit interruptions becomes a rough method of classifying recovery rate conditions.

On page 536 of the paper, however, it is pointed out that high frequency oscillations of small amplitude are of no consequence as the voltages associated with them can do no harm. It is suggested there that voltages below 40 per cent of the total amplitude (this is close to the root mean square value of rated voltage) could be neglected in a more accurate interpretation of the recovery characteristic. This fact is due to the rapid strengthening of the dielectric immediately following interruption at a current zero, which strengthening Slepian has assumed to start linearly before the current is interrupted.

C. L. Fortescue and Van Sickle both have referred to the agreement of their experimental data obtained from a cathode ray study and calculations using the curves and tables presented. This observed agreement is encouraging; however, I believe that the same agreement would have been obtained by using previously published methods provided they were manipulated to a result free from error and lengthly corrections. If the tedious mathematics of recovery rate calculations has been shortened by reason of the curves and tables presented, then one of the main objects of the paper has been realized.

L. V. Bewley's analysis showing the reduction in magnitude and rate of rise of the recovery voltage obtained by shunting a current limiting reactor with "thyrite" resistors is appreciated. This method of controlling the recovery rate has been used in interrupting tests using a long water tube resistor across the reactor with results which were in agreement with the preliminary estimates.

In conclusion the author wishes to point out that because of the equivalence of the common field recovery circuits as shown in table II, making it possible to reduce all field circuits to the simple series circuit of figure 4*d*, means have been suggested for rapidly determining these 2 frequencies from the open terminals of a circuit breaker in the substation. Instruments, to be used with a portable visual type cathode ray oscillograph, are being considered for this purpose.

A Cathode Ray Oscillograph for Observing 2 Waves

Discussion and authors' closure of a paper by R. H. George, H. J. Heim, H. F. Mayer, and C. S. Roys published in the October 1935 issue, pages 1095–1100, and presented for oral discussion at the high potential measurements session of the Great Lakes District meeting, West Lafayette, Ind., October 25, 1935.

C. M. Foust (General Electric Company Schenectady, N. Y.): The electronic switching circuit for simultaneous observations of 2 waves is an ingenious method of overcoming the shortcomings of the rotary-switch synchronous-motor arrangement. The electric switching is capable of better precision in timing and is much more flexible in application. As the authors point out, frequency and power supply limitations of the synchronous motor arrangement are largely eliminated. Some criticism of the use of the word "simultaneous" may, however, be justified here. Actually, of course, the cathode beam is acted on by but one signal voltage at a time and what appears as a simultaneous observation on the fluorescent screen is a record of succeeding and not simultaneous waves. As pointed out by the authors, one solution of the problem is a multiplicity of cathode beams, each deflected independently and simultaneously. This appears to be the ideal solution.

The cathode ray oscillograph described is interesting. It is noted that the authors have recently decided from calculations that a sharp focus may be obtained in a

hard vacuum. As announced quite some time ago, our work along this line has resulted in the production of a high-voltage hot-cathode sealed-in tube for outside photography. Long-time runs on a number of these tubes have now been completed and the latest design has been demonstrated to have long life at high voltage operation.

This tube has been incorporated in a general purpose cathode ray oscillograph which is capable of writing speeds sufficiently high for impulse testing with the standard waves now used. This development we believe to constitute a substantial step forward in oscillograph design. The elimination of vacuum adjustments and difficulties greatly facilitates the general technique and broadens the field of usefulness of the cathode ray oscillograph.

R. H. George, H. J. Heim, H. T. Mayer, and **C. S. Roys:** C. M. Foust's objection to the word "simultaneous" can be removed by referring to the particular effect secured as "apparently simultaneous."

With reference to the multiple beam idea as the ideal solution, it is understood that the use of the cathode ray oscillograph in connection with surge studies is under consideration. In this regard, the authors are well aware that the application of the electron tube switching arrangement is limited to recurrent phenomena, either transient or steady state. We are glad to learn that a high-voltage, sealed-off cathode-ray tube for transient recording has been produced which has long life. This is a very important contribution to the oscillograph art.

The Production of Impulse Test Voltages

Discussion and author's closure of a paper by C. S. Sprague published in the October 1935 issue, pages 1100–04, and presented for oral discussion at the high potential measurements session of the Great Lakes District meeting, West Lafayette, Ind., October 25, 1935.

Theodore Brownlee (General Electric Co., Pittsfield, Mass.): Electrical engineers who work with impulse generators and cathode ray oscillographs are gradually accumulating a store of knowledge concerning their possibilities and limitations. However, the number of laboratories using this equipment is small and there is far too little interchange of ideas among the different groups which are working along common lines. For these reasons any new descriptions of laboratory technique are very welcome.

Sprague, while recognizing the complexity of any impulse circuit, has shown how under some conditions the wave shapes check closely the calculated values for the simple series circuit of lumped constants. This circuit gives an equation for the voltage across the resistance in the form $A(\epsilon^{-mt} - \epsilon^{-nt})$ which is the simplest possible equation for a wave having both a front and tail. As has been shown before ("Laboratory Measurements of Impulse Voltages," J. C. Dowell and C. M. Foust, A.I.E.E. TRANS., v. 52, June 1933, p. 537–42) the same type of wave can be obtained using a circuit of resistors and capacitors only. In a more general form this circuit is shown in figure 1 of this discussion.

The equation for the voltage across R_2 is:

$$EC2 = \frac{E}{RC2} \times \frac{1}{n - m} [\epsilon^{-mt} - \epsilon^{-nt}]$$

where $m = \alpha - \beta;\ \ n = \alpha + \beta;$

$$\beta = \sqrt{\alpha^2 - \omega_0^{\,2}}$$

$$\alpha = \frac{1}{2}\left[\frac{1}{RC} + \frac{1}{RC2} + \frac{1}{R_1C1} + \frac{1}{R_2C2}\right]$$

$$\omega_0^{\,2} = \frac{1}{C1C2}\left[\frac{1}{R_1R_2} + \frac{1}{RR_2} + \frac{1}{RR_1}\right]$$

Either R_1 or R_2 may be infinite in which case there is one less term in the brackets for α and ω_0^2.

This circuit neglects any inductance which may be in the resistors and connections, and like the circuit described by Sprague, may or may not have appreciable oscillations superimposed on the main wave. In no case is the circuit as efficient in an energy sense because in the *CLR* circuit all the energy available is dissipated in the resistor across which the desired wave is obtained, while in the capacitance-resistance circuit some energy is lost in all the resistors. However, for a given wave and impulse generator capacitance, the inductance and resistance are fixed for the *CLR* circuit, while in the capacitance-resistance circuit there are an infinite number of combinations that can be used, thereby giving more latitude to the operator in setting up his circuits. This latitude is in some degree offset by the difficulty of recalculating the circuit by cut and try methods every time one of the constants is changed. Practically, it is easier to experiment than to calculate in trying out this circuit since it is necessary to take oscillograms anyway to see if oscillations are present or not. The writer has secured very smooth 1 x 5 and $1^1/_2$ x 40 microsecond waves using a high resistance for R so that about half of the available voltage was obtained across $C2$. Lack of time has prevented the determination of the practical limits to the voltage efficiency that can be obtained.

An example of the possibilities of this circuit is given in figure 2, which shows approximate 1 x 5 microsecond waves of both polarities. These waves were used to determine the arc-over strength of porcelain and some breakdowns are shown on the crest and tail. The circuit constants were roughly measured as given in figure 2 and the resultant calculation gives a 0.9 x 4.5 microsecond wave.

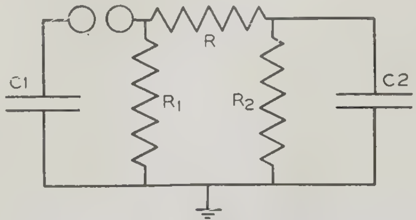


Fig. 1. Impulse circuit of resistance and capacitance

No one who works with impulse generators doubts that traveling waves exist even in the most simple and compact circuits,

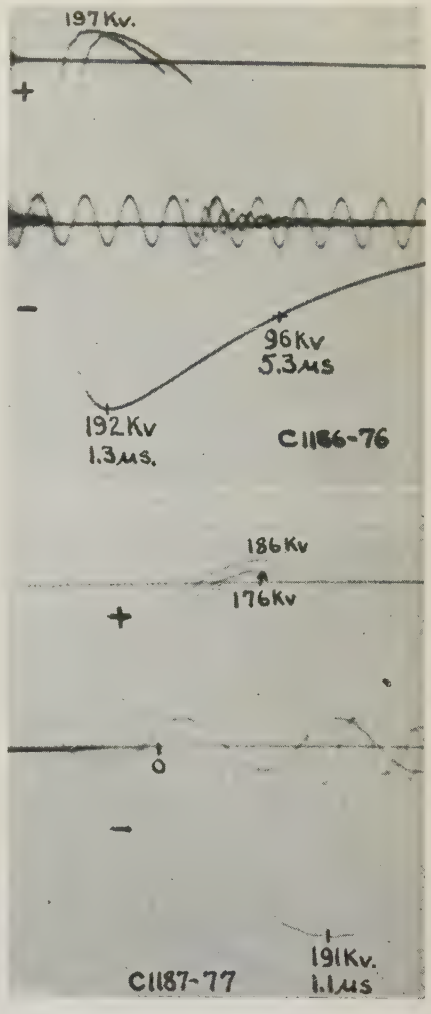


Fig. 2. Oscillograms showing approximate 1 x 5 microsecond waves

C1 = 0.028 microfarad
C2 = 0.00054 microfarad
R = 850 ohms
R_1 = 167 ohms
R_2 = 2,000 ohms

and the general rules set down by Sprague to minimize them are not contradicted. However, it is doubtful if an inductance coil can be considered analogous to a transmission line because it has both mutual inductance and capacitance between turns as well as the self-inductance and capacitance to ground of the individual turns. It seems entirely plausible that a very short (less than $0.4D$) large diameter coil might, because of the larger magnetic and electrostatic coupling between turns, have less traveling wave effects than the maximum efficiency coil of the same inductance. It is unfortunate that Sprague has not shown oscillograms or rigorous mathematical proof to substantiate the assertion that "with a greater length of wire (than that for the most efficient coil shape) in the inductance the period of reflections will be greater and

the individual reflections will be more pronounced."

Sprague's conclusion "For any turn spacing the diameter which provides a given value of inductance with a minimum length of wire is such that the ratio of the axial coil length to the diameter is approximately 0.4" is stated in reference 15 of the paper. However, it is far from necessary to increase turn spacings if coils do not withstand the impulse voltage. The flashover voltage depends primarily upon the coil length and of 2 coils having the same over-all length and same inductance, the coil having the closer spaced turns and smaller diameter will be found to have the shorter length of wire. In the lightning arrester laboratory in Pittsfield a single layer of closely spaced turns of double cotton covered enameled copper wire is used of a size sufficient to carry the current and with a spool long enough to withstand the voltage. As a rule about one foot per 100 kv is sufficient. Ordinarily this results in a coil of but a few inches in diameter which is easy to handle and requires little space in use or in storage. The completed coils are given 2 coats of shellac to impregnate the cotton covering and protect it during handling.

Often there is one more advantage of a narrow closely spaced coil over a large diameter coil of the same over-all length and inductance. This is that the small diameter coil produces less electromagnetic field at moderate distances away from the coil even though inside the coil the field is more intense. This is of considerable importance when the impulse generator is located near the oscillograph as it is practically impossible to shield against deflections produced by strong magnetic fields.

For voltages up to 100 kv where a high inductance is needed, we have even used a 2 layer bank wound coil. However, unless a very low resistance is required, the same inductance can be secured much quicker by using the same size spool and a single layer of wire of half the diameter used in the bank wound coil.

C. S. Sprague: Theodore Brownlee indicates some advantages of the "resistance control" method over the method of "inductance control." The chief of these advantages seems to be the wide latitude of possible combinations which the operator may use to obtain the desired wave shape, assuming, of course, that a high-voltage variable capacitance is available for $C1$ as shown in figure 1 of the discussion. Brownlee states that smooth waves (1×5 and $1\,{}^1/_2 \times 40$ microseconds) were obtained using a high resistance for R so that about half the released voltage was available across $C1$ for testing purposes. Neglecting the poor voltage efficiency of the circuit it is the author's opinion that high resistances between the test piece and the main capacitor of the surge generator are very undesirable. As shown by J. J. Torok and F. D. Fielder ("Ionization Currents and the Breakdown of Insulation," A.I.E.E. JL., v. 49, Jan. 1930, p. 46–50), the process of insulation breakdown is accompanied by streamer currents of large magnitude during the breakdown period. High series resistances will tend to limit the current which the generator may supply and consequently affect the impulse breakdown voltage, especially on the crest or front of the wave. This point was further emphasized during some tests at Purdue University to determine the effect of ultraviolet radiation upon the time lag of sphere gaps. The time lag of the gap itself could not be studied until the apparent time lag caused by series resistances had been reduced to a minimum.

As stated in the paper, the analogy of a surge traveling through an inductance coil with a surge on a transmission line is only a fair analogy. Without doubt the process is complicated by the mutual inductances between turns and by the various capacitances between turns and to ground. In spite of this, the voltages built up across a resistance connected between the end of the inductance coil and ground show either positive or negative reflections with the amplitude of the reflections increasing with the value of resistance. This seems to be sufficient justification for the use of this analogy for the purpose of illustration.

Brownlee states that for equal inductance values and equal axial lengths of coils, the coil having the closer spacing between turns and the smaller diameter would contain the least wire. This is true and from this standpoint the smaller coil would be more desirable. It is further stated in the discussion that the flashover voltage depends primarily upon the coil length, implying that the 2 coils would have equal flashover strengths. This has not been the author's experience, but, over the range of spacings and coil lengths thus far studied, the coil with the closer turn spacing would tend to flash over first. Complete flashover of the coil seldom occurs, the breakdown usually being confined to the end turns. Possibly the discusser's practice of using double cotton-covered enameled wire covered with 2 coats of shellac provides enough additional solid insulation between turns to allow the use of closer spacing and smaller diameters.

Effect of Ultraviolet on Breakdown Voltage

Discussion and author's closure of a paper by G. L. Nord published in the September 1935 issue, pages 955–8, and presented for oral discussion at the high potential measurements session of the Great Lakes District meeting, West Lafayette, Ind., October 25, 1935.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The comprehensive treatment of the effect of ultraviolet irradiation on the breakdown voltage of the 6.25 centimeter sphere gap, in relation to gap spacing, steepness and form of impulse wave, metal of electrode, light intensity, etc., renders this contribution on the sphere spark gap of both practical and theoretical interest. The data in table I have a practical bearing in establishing recommendations on the use of ultraviolet irradiation with sphere gaps when these are employed to measure low voltages. Though these data apply for negative impulses, it hardly would be expected that positive impulses would give appreciably different results. It is desirable, however, to have similar tabulations for negative and positive impulses and 60 cycle voltages, corresponding to the various sphere gaps, perhaps for those gaps which are a size smaller and larger than the 6.25 centimeter diameter.

An investigation on the effect of ultraviolet radiation on the breakdown voltage of the 50 centimeter brass sphere gap with a 1.5 x 40 microsecond negative wave was made by F. D. Fielder over a year ago. The results obtained are tabulated as follows:

Date	Spacing, Centimeters	Kilovolts With Arc*	Kilovolts Without Arc
8–23–34	30	573	577
	35	620	621
	40	650	655
	45	683	682
8–24–34	40	659	662

* Open carbon arc light placed 100 centimeters from lower sphere at about same level as lower sphere. Arc directed upward to upper sphere. Arc current 25 amperes
Bottom sphere movable and grounded

The voltages were measured at the cathode ray oscillograph by means of the resistance-cable divider. The values given are average figures from a number of oscillograms, the voltage of individual oscillograms being within one per cent or less of the average value. No appreciable improvement in the consistency of individual readings could be observed when the gap was preionized. These and Nord's data thus establish the fact that preionization affects the breakdown voltage of sphere gaps inappreciably above a certain voltage.

Abe Tilles (University of California, Berkeley): The author presents a most interesting and timely paper. A few pertinent items are not entirely specified, giving rise to the following questions:

1. Has "the then accepted calibration of the sphere gap" utilized the A.I.E.E. Standard No. 4, or is it possibly P. L. Bellaschi and P. H. McAuley's calibration ("Impulse Calibration of the Sphere Gap," *Elec. Jl.*, v. 31, June 1934, p. 228–32) at impulse sparkover?
2. Is table I a "50 per cent sparking" measurement?
3. What is the approximate energy dissipated in the spark at each of the 3 voltages of table I?
4. To what extent, and how often, was cleansing of the electrodes necessitated? What visible evidence was there of this need and what cleansing procedure was utilized?

May I suggest that in figures 1 and 2 the designation "breakdown voltage" for the plot of various measured values of the identical voltage tends to be misleading. Might not a designation such as "apparent breakdown voltage" or "apparent voltage measurement" be better?

It has been my experience that the quartz mercury arc is not only, as stated, more convenient than the carbon arc, but also much more powerful in its photoelectric effect. Further, keeping the watts input into a quartz mercury arc constant under usual operating conditions insures that the output will be constant only to a very rough approximation, *e. g.*, ±30 per cent. For fine control it is very desirable to measure the resultant photoelectric effect more directly.

Table I gives a striking assembly of data. As the author points out and explains in his summary, particularly for the smallest gap length, the voltage waves which have a more rapid decay show the more pronounced effect of time lag on spark-over. Further, the tabulated data show, and this the author does not definitely state, that the voltage wave which has a more rapid rise shows a less pronounced effect of time lag on spark-over. This observed effect, for example, 52 per cent voltage for the 1 x 5 wave and 66 per cent for the $^1/_2$ x 5 wave. neither irradiated, at approximately 9 kv, is readily understood. One needs merely to recall that, if the voltage rise were sufficiently rapid, the initially present electrons would not have time to leave the gap before break-down voltages were reached and the initiatory time lag would therefore be diminished to zero. Accordingly, the more rapid the voltage rise is, the more likely is it that initially present electrons will be effective in producing spark-over, and that the initiatory time lag will be eliminated.

In conclusion 7 of a recent paper ("Spark Lag of the Sphere Gap," Abe Tilles, ELEC. ENGG., v. 54, Aug. 1935, p. 868–76) it was suggested that experiments such as these be undertaken to determine what constitutes an adequate ionizing source for various gaps. It is most gratifying to observe that these experiments carry the matter to completion in one regard. It is shown that the small quartz mercury arc is adequate over the useful and severe range of wave shapes studied and for voltages between 10 kv and 80 kv.

It is to be noted from the data presented that at approximately 9 kv while improvement produced by the arc is substantial, it is hardly altogether adequate, since errors of 9 per cent still remain. For larger voltages and gap lengths, as pointed out by the author, the effects of the geometry alone definitely tend to make the need for irradiation much less severe. Practically, however, spark-over with larger amounts of power may well act to substantially diminish the electron emissivity of the electrodes in various ways. Accordingly, direct experimentation at higher voltages is as much in order as ever, and after the excellent example which the author has given such experiment should be considerably easier than previously.

C. S. Sprague (Purdue University, West Lafayette, Ind.): From the data presented in the paper it would seem that the beneficial effect of ultraviolet radiation and the increased accuracy obtained by irradiation of the small sphere gaps is amply demonstrated. Although the most striking results were obtained using a special type of wave having an overshooting crest, there is, nevertheless, some considerable advantage in the use of ultra violet radiation even for the 1 $^1/_2$ x 40 microsecond wave. It is, furthermore, true that some types of impulse testing require the measurement of the crest voltage of a wave wherein the wave voltage may be suddenly reduced either on the wave front or at the crest, and for this case, the necessity of using ultraviolet radiation can scarcely be questioned.

The effect of increasing the intensity of the radiation is that of causing the measured voltage to become asymptotic to a voltage which is shown to be the actual crest voltage of the wave; hence the use of ultraviolet radiation can never cause the measured voltage to be greater than the actual. In other words, the radiation has no effect upon the critical gradient of air, but merely serves to supply the electrons necessary for ionization when the proper gradient is reached.

With respect to use of ultraviolet radiation upon large spheres at large spacings, some tests have been made but have failed to indicate any consistent increase in accuracy. There seem to be 2 probable reasons for this. The first is the difficulty of producing an intense ultraviolet radiation in the strongest part of the field, since the source must be kept at some considerable distance from the gap under high voltage conditions. The second is that there often exists an apparent time lag which is not due to the gap itself, but is due to the regulation of the circuit supplying energy to the gap. In other words, the impulse generator, due to series resistance and reactance, may be incapable of supplying energy to the gap as fast as the gap would otherwise absorb energy. This condition appears to be more serious when a considerable amount of energy must be supplied to a large volume of air, as is the case with large spheres at great spacings. It is obvious that this apparent time lag must be minimized before the effect of ultraviolet radiation can be determined.

J. E. Hobson (Enrolled Student) and **R. B. Vaile, Jr.** (Iowa State College, Ames): The qualitative effects resulting from the irradiation of small sphere gaps have been recognized for some time, but the author is to be commended for furnishing concrete data illustrating the quantitative results of such irradiation.

Referring to figures 1 and 2 of the paper, the marked curvature of the curves near zero radiation intensity may possibly be explained by the selective frequency absorption of air. The frequency, as well as the intensity, of the radiation incident on the sphere surfaces is changed as the radiation source is moved farther from the spheres. This point might be checked by obtaining curves of intensity versus lamp distance with the filters immediately in front of the photoelectric cell rather than near the light source.

It is to be expected that the presence of the grounded lamp would introduce some distortion of the electrostatic field. On the assumption that the discharge is initiated at the negative sphere, the approach of the lamp should produce a rising curve if the ungrounded sphere were negative as was the case in Nord's experiment; and a drooping characteristic if the hot sphere were positive. This may account for the somewhat rising characteristic of his curves. We should like to ask him if he has taken any data with the lamp dark in the field at varying distances from the spheres. Evidently the ordinates of figures 1 and 2 should be labeled "breakdown spacing" rather than "breakdown voltage."

We feel that sufficient emphasis was not given in the paper on the author's use of a testing wave having high crest oscillations. Such waves undoubtedly exaggerate the time lag of small spheres at the spacings used for this investigation. The legitimacy of the use of such waves is not questioned, for the beneficial properties of irradiation are made more apparent. It should be noted however, that such waves are not in general use for routine testing.

The results of the research leave no doubt as to the necessity for irradiating small spheres at small spacings; what are the author's opinions as to the range of sphere sizes and spacings for which illumination is desirable?

The paper emphasizes the conclusion that the diminution of time lag is more a function of radiation frequency than of intensity, thereby confirming the author's statement that the phenomenon is primarily that of photoelectric emission rather than ionization of the gap.

It would be interesting to extend the research to a study of the behavior of rod gaps and other forms of electrodes. We have found that the standard N.E.M.A. rod gap setting had to be changed several inches to discharge simultaneously with a 42 inch protective gap when the former was situated in bright sunlight. Furthermore, the gaps did not behave similarly when both were under the same conditions of exposure to sunlight. The unusual performance could be attributed at that time to no factor other than the irradiation of the gaps.

This paper is a definite forward step in the standardizing of impulse testing technique. The question may now well be asked as to how far we are justified in extending precision measurements to surge voltages. It would seem that a primary standard of surge voltage measurement is not of paramount importance at present. It is inappropriate to make standard measurements in the laboratory, since the surge overvoltages encountered in practice vary greatly both in crest value and wave shape. It is of the greatest importance, however, that testing technique be standardized among the laboratories, in order that comparable data may be obtained. A primary standard of power frequency voltage measurement is of pressing need for 2 reasons:

1. Power frequency overvoltages do not extend over such wide ranges and it is possible to operate insulating materials nearer the limiting voltage.

2. Accurate voltage measurements will be of great aid in extending a theoretical study of the breakdown behavior of insulating materials. No extensive or conclusive study of such nature has been made. It seems probable to us that the breakdown phenomena are similar for either surge of power frequency voltages.

We believe the sparkless sphere gap voltmeter as developed at the California Institute of Technology may be of considerable application for such studies as that just mentioned. Almost daily use of the apparatus has convinced us of its value both as a precision instrument and as a meter for routine test work.

K. B. McEachron (General Electric Co., Pittsfield, Mass.): As indicated by the author, the use of irradiated gaps of small spacing, where duplicability of flashover is required, is old in the art. It was used by the writer to give more accurate and consistent breakdown to gaps used in connection with the paper "Measurement of Transients by the Lichtenberg Figures" (A.I.E.E. TRANS., v. 45, 1926, p. 712–17. See

figure 3). It is used quite commonly in the initiating circuits of our impulse generators, using the Marx circuit to give precision in initiation. A quantitative study of the effects of ultraviolet on the impulse performance of small spheres is of particular interest at this time, in view of the work now in progress by the subcommittee on sphere gap calibrations leading to new calibrations for sphere gaps.

The relationships shown in figures 1 and 2 are not quite clear, since the text states that these figures show the increase in gap length and breakdown spacing with relative radiation intensity. The curves appear to be plotted in kilovolts versus relative radiation intensity. Perhaps the kilovolt values are related to spacing, as given in the standard A.I.E.E. tables for 6.25 centimeter spheres. Whether the spacing was held constant, and increasing potential read from oscillograms, is not clear.

From what is known by experience about the erratic breakdown of small gaps without radiation, the results appear to be logical as shown by the oscillograms in figures 4, 5, and 6, and show plainly the advantage of providing proper radiation.

Apparently, if I have interpreted figure 2 correctly, the results with no filter were most satisfactory. Although no conclusion is drawn, the results seem to indicate that an intensity of between 20 and 30 would be satisfactory, which means an equivalent of approximately a 35 watt source placed 7.5 inches from the gap and perpendicular to it. In our work, we have used somewhat larger light sources placed further away, which is of course necessary with higher potentials. We are using a mercury arc to irradiate the first gap (initiating gap) on our impulse generators. Approximately 40 watts is dissipated in the arc at a distance of 20 inches from the gap. The gap irradiated is a 3 electrode gap of 3 inch diameter spheres. It is used for a range of voltage from 25 to 150 kv. The operation of the gap is decidedly more consistent with the radiation, allowing more accurate timing of the impulse wave and the oscillograph.

It is now well known that large spheres with spacings within their normal measuring range have some time lag when the wave applied is steep enough. Perhaps radiation of the negative sphere would reduce this time lag to a sufficient degree to overcome the difficulties involved when working at high voltages.

The results given in this paper clearly point to the necessity of giving consideration to specifying suitable radiation for the small sphere gap spacings when used as a spark gap for determining potential.

On larger size spheres, the problem of reducing the time lag might be more difficult. Due to the higher voltages applied to the spheres, the source of radiation will have to be moved further away, and the intensity of radiation will be considerably reduced. Some tests made with 25 centimeter sphere gaps, with a wave front rising at the rate of approximately 700 kv per microsecond (breakdown at 0.5 microsecond), did not show any difference in breakdown voltage for 8 centimeter and 4 centimeter spacings when the spheres were irradiated, although the measured overvoltage was of the order of 150 per cent. The quartz mercury arc lamp during these tests was placed 18 inches from the spheres and 60 watts were dissipated by the lamp. To obtain results comparable to small size spheres, it appears to be necessary to use stronger sources of irradiation to procure a considerable reduction in time lag.

G. L. Nord: The many comments received are very encouraging, and for better understanding, I will attempt to answer the discussions.

Abe Tilles brings out a few points which perhaps should have been included in the paper. The calibration curves used for the 6.25 centimeter sphere gap were the A.I.E.E. standard 60 cycle curves. The data in table I was obtained from 50 per cent spark-over measurement. With regard to the current dissipated in the spark, there was, of course, resistance in series with the sphere gap; not enough to make an apparent time lag, yet limit the current so that it would not be necessary to clean the spheres so often. The spheres were cleaned before the start of each test and after a few measurements were taken. No test was made to determine how often they should be cleaned since it only took a few minutes for cleaning. The procedure for cleaning was to use a fine metal cleaning paste and polish the spheres thoroughly. After this the spheres were washed with alcohol and ether.

Tilles suggests that the ordinates of figures 1 and 2 might better be designated as "apparent breakdown voltage." I disagree with this since the voltage plotted on these curves was actually measured by the sphere gap with 50 per cent sparking measurement. These ordinates are breakdown voltage as measured by the sphere gap under certain conditions.

With regard to Tilles' point about the constancy of the mercury vapor lamp light output, I used a photoelectric cell in series with a microameter to obtain the relative light intensity. The cell was of the type sensitive to visible light and part of the near ultraviolet. By first keeping the current input fairly constant, there was a variation of the light intensity as recorded by the cell. Keeping the watts input constant decreased this variation to a very small amount. Of course, the assumption was made that if the visible radiation of the lamp remained constant, the ultraviolet radiation would also remain constant. A small thermopile patterned after those made at the United States Bureau of Standards was also used to a certain extent.

A further conclusion which Tilles draws from the data of table I may be all right from the data presented but it must be remembered that without light the readings were erratic, inaccurate, and varied considerably. Accordingly, 14 per cent is small, considering this variation.

J. E. Hobson and R. B. Vaile, Jr., suggest introducing the filters immediately in front of the photocell. The photocell was not calibrated for ultraviolet light in this instance and I doubt whether it would record much change in relative intensity since the frequency change of the light which the photocell is sensitive to, would in all probability not be much. A method of measuring the intensity with an instrument not effected by frequency and sensitive only to the ultraviolet range would probably be the instrument to use. Even if there were a marked change in frequency, when the light was far away, it would probably be all right for the object of increasing the distance between the lamp and the spheres was to gradually reduce the radiation's effect on the breakdown voltage of the sphere gap.

When readings were taken without irradiation, the lamp was left at the required distance. A few times the lamp was taken away altogether for readings without irradiation, but no change in the breakdown voltage was noted. If there were a change, it would have to be marked, due to the erratic readings obtained without radiation on the spheres.

Although no tests were made on the 2-centimeter spheres, it is probable that irradiation is needed for increased accuracy when measuring surge voltages of the types of waves used in this paper. A few tests were made, previous to these, on the 25 centimeter spheres, which showed that ultraviolet radiation had some effect. No oscillographic tests were made with the 25 centimeter spheres. The data given in P. L. Bellaschi's discussion tends to show a decrease in effect using larger spheres at correspondingly larger spacings.

To clarify a few points brought out in K. B. McEachron's discussion, I wish to state that for each curve in figure 1 and for the curves in figure 2 the voltage wave was held constant. In other words, no change was made in the generator voltage. The radiation intensity was varied, which resulted in varied readings of the sphere gap for the same generator voltage. No oscillograms of these tests were taken other than to note the type of wave and crest voltage.

Before any standards can be set for the intensity of ultraviolet radiation to be used on particular sizes of spheres and for definite voltage limits, I believe that more work should be done with possibly higher intensities of ultraviolet if not with shorter wave lengths. It would be interesting to note the results of using soft X rays.

Lightning Investigation on Transmission Lines—V

Discussion and authors' closure of a paper by W. W. Lewis and C. M. Foust published in the September 1935 issue, pages 934–42, and presented for oral discussion at the high potential measurements session of the Great Lakes District meeting, West Lafayette, Ind., October 25, 1935.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This fifth paper by these authors presents us with further valuable data regarding the performance of lines under lightning conditions. These data, it seems to me, corroborate the fundamental correctness of the analysis of lightning troubles during the past few years. I am in agreement with the general conclusions. Such points in which I differ from them are brought out in this discussion.

Regarding the authors' discussion of the possible potential difference across a vertical section of tower, I have doubts whether their method of measuring the drop across a 40 foot length of the tower will give correct values especially when the current in the

tower has a very steep wave form. We have records of very steep waves fronts on surges, as for example the oscillogram obtained at our Ogemau station in Arkansas. This wave after traveling over the transmission line for $4^1/_2$ miles had a crest of 5,000 kv with a 2 microsecond front. It does not seem to me improbable that the current in a severe stroke may rise in 1 microsecond to a crest value of 200,000 amperes, in which case if such a stroke current occurs in a steel tower 100 feet high the inductive drop in the tower would be of the order of many times 100 kv, which the authors have cited as an upper limit. I think Philip Sporn has records of insulation flashover of well shielded lines with low tower footing resistance of $1^1/_2$ ohms which could hardly be accounted for unless there was a high inductive drop in the tower. This inductive drop will occur during the building up of the current and will then drop to zero or a small value of reverse polarity with the decay of the current in the tower. I am using a simple formula for this inductive drop which checks up quite closely with values derived by the method of reflection:

$$V_T = \frac{h}{1000} Z_T \frac{I_G}{T} \text{ volts}$$

where T is the time in microseconds for the current to reach its crest, I_G is the crest value of the current in the tower footing, h is the height of tower in feet, and Z_T is the surge impedance of the tower, which on the average for steel towers may be taken as 100 ohms.

We have attempted to simulate in our Trafford laboratory the conditions that arise when lightning strikes a ground wire at midspan. We have not succeeded in obtaining side flash to another conductor parallel to the ground wire even with quite low separation. The formation of corona and reflection from adjacent towers apparently combine to keep the potential difference low enough to prevent side flash even with such low spacings as 16 feet. However, I prefer for important lines a more conservative separation of from 25 to 30 feet and to insure good shielding by displacing the ground wire as little as necessary from a vertical position above the line wires.

The authors have presented further data confirming the importance of keeping the tower footing resistances low to render the overhead ground wires effective against direct strokes; this value for a line insulated with 14 to 16 insulators appears to be of the order of 10 ohms. Their short paragraph on the effect of counterpoises in reducing the tower potential is interesting and will assure those who have adopted these measures in rehabilitating transmission lines, where normal tower footings have been high, of their effectiveness.

The mechanism of the lightning stroke as disclosed by the Boys camera is, as the authors state, complicated, but it seems to me that the simple artifice of considering the channel formed by the leader stroke as having a surge impedance gives a sufficiently close approximation to the actual mechanism for all practical purposes. In this case the leader stroke may be regarded as a standing wave until a transmission line is reached after which it may be resolved into 2 equal traveling waves, one moving down the channel and at the junction of the channel with the line at which the leader stroke terminates being reflected and refracted according to the laws of traveling waves in wires, while the other travels in the opposite direction into the cloud. The potential of the traveling waves will then be half the potential of the standing wave where it impinges on the transmission line, and these waves will be further modified by reflection and refraction. The stored energy in the channel is thus converted into both kinetic and potential energy in the traveling waves and the current associated with the downward traveling wave will produce intense luminescence in the portion of the channel where it is present, which is the portion between the point of stroke on the transmission line and the receding tail of the upward traveling wave. This gives the appearance of a discharge moving upward from the point of stroke in the direction of the cloud; however, the real discharge of energy is downward in the channel from cloud to earth. When the cloud is negative the potential of the leader stroke will be negative and the potential of the component traveling waves will also be negative. The component moving in the direction of the earth, which is the one we are concerned with in our transmission line performance, will have a current associated with it in the channel which will flow in the opposite direction in the channel so that the direction of the currents in the towers will be from the tower footing upward. But in my estimation a wrong idea is conveyed by saying that this current is discharged by the earth to the cloud; it is sufficient to state that this direction of current is associated with the traveling wave of energy which emerges from the channel after the initial stroke has reached the earth, and its source is the negatively charged cloud. That the velocity of travel of the component waves is considerably modified by the gaseous nature of the channel is to be expected.

In the paper "Lightning Discharges and Line Protective Measures" (C. L. Fortescue and R. N. Conwell, A.I.E.E. TRANS., v. 50, Sept. 1931, p. 1090–1100) the mechanism of the lightning stroke from a negative cloud is discussed. It does not differ essentially from the experimental facts determined later by Schonland with the Boys camera. The velocity of propagation of the initial streamer was estimated from the speed of propagation of streamers between 2 spheres in Torok's experiments to be of the order of 1/20 the velocity of light. I did not venture to say at what speed the receding wave progressed up the channel after the initial streamer reached earth; Schonland's experiments indicate this velocity to be of the order of $^1/_{10}$ that of light. Of course, the surge produced in the line that is struck will tend to have a velocity equal to that of light except as influenced by corona and the proximity of the earth's surface. The analysis of the currents induced on towers subsequent to the stroke follows the theory of propagation of traveling waves and is in general straightforward. In treating this phenomenon there is no obscurity as to the direction of the traveling energy wave which, since it comes from the negatively charged cloud, has a negative potential, and the current associated with it in the channel and subsequently in the tower has a direction opposite to the direction of travel. Such awkward and misleading expressions as lightning current emerging from a tower are avoided and the true sequence of events preserved.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): Some 10 years ago when the first intensive research on lightning was started on transmission lines, the effort was concentrated on measuring the magnitude of the lightning voltage on the line wires. Measurements also were made of the voltage of the tower top with reference to the ground in the hope that some indication might be given of the lightning stroke voltage. This latter method of approach was negative, indicating some 35 kv as the tower top potential. Lightning voltages on the line wires were recorded in magnitudes of the same general order as the flashover of the insulator assemblies. This was on steel towers. On wood pole assemblies, as would be expected, values several times larger were measured.

The idea of measuring lightning currents in the transmission towers and conductors was not attempted at that time, although measurements of current discharges through lightning arresters were attempted. It soon became apparent that more insight into the lightning problem could be gained by a knowledge of the lightning currents in the transmission chain, and the concentration of field research has been in this direction during the past few years.

The initial results of measurements of lightning currents in tower structures gave results which did not check our then existing theories. Thus, when measured currents multiplied by the tower footing resistances gave potentials across insulator assemblies, which indicated line flashovers should have occurred, in actual practice they sometimes flashed over but at other times they did not. We were thus confronted by a situation where new field data obtained with measuring devices, that admittedly were not precision devices, failed to check with our ideas and theories about lightning, and it was necessary, therefore, to re-examine our theories and continue our measurements.

The use of the lightning current measuring devices was extended in the field, and more study was given to the theory of the lightning discharge itself and how it got on the line, and how it behaved when once there. This year, on our own system, we have extended the use of the surge crest ammeter to measuring the lightning currents in more of the possible current paths: in the different parts of the towers, in the ground wires, in counterpoises, and where possible in the complete lightning stroke itself. For example, we erected several years ago tower top lightning rods on some 80 towers in an attempt to measure the current directly in the stroke itself. This year we have added magnetic links not only to measure currents in counterpoise wires where they attach to the towers, but also at points along the length of the counterpoise wires. Also, we have added magnetic links to the ground wires in a number of locations to determine whether the theory that the current in towers adjacent to the one apparently struck has been transmitted solely over the ground wires. The data obtained during

the past year have not been thoroughly analyzed as yet, but they give promise, from preliminary study, of giving some valuable new information on the effect of ground wires and counterpoises in protection against lightning.

The need for continued field research on natural lightning phenomena on transmission lines is clearly brought out from the data presented in tables I and II of this paper. From table I, during 1933, 9 tower currents were recorded above 30,000 amperes and only 2 in 1934. The probable stroke currents are 2 above 50,000 amperes in 1933, and 1 in 1934. On the Glenlyn-Roanoke line (table II) there are 2 tower currents above 30,000 amperes in 1933 and 27 in 1934; while the probable stroke currents are 2 above 50,000 in 1933 and 14 in 1934. It is clear then that it is important to have a fairly definite knowledge of not only the magnitude but of the frequency of the lightning currents actually encountered in the field if better line protection, whether by lightning arresters, expulsion protective gaps, low tower footing resistances, counterpoises, or other devices, is to be attained.

The record of the Victoria Falls 132 kv line with the one ground wire placed 18 feet above the top conductor, wherein the authors have expressed the opinion that poor shielding has resulted in spite of this large spacing, is most interesting. While this record does not fit in with some of the more recent theory on the best method of locating ground wires, we certainly cannot ignore the particular operating records.

Although we have made vast strides in obtaining a better understanding of lightning phenomena in recent years, there is still much field of analytical work to be done before we can predict the lightning performance of a line with as much certainty as we can the characteristics or performance of a turbine, a transformer, or a similar piece of equipment.

C. S. Sprague (Purdue University, West Lafayette, Ind.): Although usually less productive of immediate results, field research is a necessary complement to laboratory investigation, and the engineering profession should be grateful to the authors and to the several associated companies for continuing this type of research during a period when the natural tendency is to cut all costs to a minimum.

One feature of the article which seemed of particular interest is the manner in which the authors have taken field data, such as stroke current and footing resistance, and combined these with laboratory data pertaining to insulator flashover, etc., to provide a logical explanation of the mechanism and sequence of the observed phenomena. It is a good illustration of the manner in which field and laboratory tests complement each other. The authors are to be further congratulated upon a clear and logical analysis of the mechanism and sequence of the phenomena associated with the direct stroke from the line with and without ground wires.

From the technical standpoint the writer would like to ask concerning the method of measuring footing resistance and also as to the justification for assuming that the measured resistance is equal to the impedance under surge conditions. The question arises from the consideration that, particularly in dry or gravel soil, the impedance under surge conditions may be lowered by spark-over from the buried conductor to the soil, which of course would not be present for low voltages at which the footing resistance might be measured. The argument, of course, has less and less weight for grounds in moist loam where it may be assumed that the ground conductor makes more intimate contact with the soil. The authors' opinions upon this point will be appreciated.

K. B. McEachron (General Electric Co., Pittsfield, Mass.): Under the heading of case I, the authors point out the effect of a negative stroke to a tower when the conductors have system potential to ground already applied. This effect, I believe, was recognized first in a paper which I presented to the Institute in 1935, which is the authors' reference 11. In that paper, tests were described briefly which confirmed the field results, showing that, as the negative potential of the tower increases the most positive conductor flashes over, first followed by those less positive, and finally, if sufficient negative potential still exists on the tower, the remaining conductors will flash over.

I pointed out in a discussion (Elec. Engg., v. 54, March 1935, p. 329–31) of a paper by Sporn and Gross, entitled "Expulsion Protective Gaps on 132 Kv Lines," that some considerable gain in protection could be made by reducing the insulation on one side of the tower, with reference to the other side, so that all 3 conductors on one circuit would flash over before any of the conductors on the other circuit flashed over.

In view of the facts contained in that discussion, it seems that a considerable reduction in double circuit outages will result from maintaining such a differential in insulation level between the 2 circuits, and that if the tower or ground wire is struck, all 3 conductors on one side of the tower will flash first, putting in parallel with the ground resistance the combined surge impedance of the 3 conductors in both directions in parallel. This effect, when combined with inductive coupling of the conductors, will offer considerable protection to the circuit with higher insulation. These relationships (excluding effects of coupling) are worked out for a 132 kv double circuit line, as shown in chart form in the discussion referred to.

In order to be sure that one circuit flashes over before the other, the difference in insulation level must be approximately 2 times the system line to ground potential. For a 132 kv system, this is 156 kv, or at least 2 insulator differentials between the 2 circuits would be required. In using such a scheme, recognition should be given to the possibility of communication of the arc between phases due to the wind. To illustrate, the air velocity with a 45 mile wind is one foot per cycle (60 cycles per second) and the switching may not be fast enough to prevent a double circuit outage if wind conditions are right. However, if flashover of the phases of lower insulation is prevented, by the use of expulsion protective gaps and sufficient insulation margin maintained between the 2 circuits, double circuit outages of ground wire protected lines largely can be prevented, even though tower footing grounds cannot be reduced to quite as low a value as was considered necessary before the effect discussed here was considered.

Of course on steel tower lines, without overhead ground wire, some of the effect is still retained if lightning strikes the conductor with the lower insulation. If flashover in the span between circuits does not take place, all 3 conductors will flash to the tower first, shunting considerable current from the tower footing resistance. If, however, the more highly insulated conductor is struck, a double circuit fault is almost certain to result at the tower. If expulsion gaps are used on one circuit at the tower, a double circuit fault can be prevented, and if the unprotected circuit is the circuit of higher insulation, some benefit will result in reduction of troubles from the paralleled surge impedances of the conductors of the protected circuit.

There is reason for the belief, based on the foregoing discussion, that simultaneous faults on double circuit lines are the result of strokes either to ground wires or towers, without sufficient insulation to correspond to the tower footing resistances involved. Single circuit faults on such lines indicate strokes to conductors, which means improper shielding by the overhead ground wires. Double circuit faults, which occur a few cycles apart, may be the result of communication by wind or of multiple strokes which may contact the second circuit.

The data given by the authors with reference to the occurrence of currents of various magnitudes are of much importance, since calculations of protection required are based upon stroke currents, rate of rise, and magnitude. Frequency of occurrence is necessary to determine the economic value of any protective arrangement.

J. R. Eaton (Consumers Power Co., Jackson, Mich.): The data summarized in figure 3 of the paper may be further extended to a study of the percentage of lightning strokes which will cause flashover on towers having known footing resistance. In the paper it is

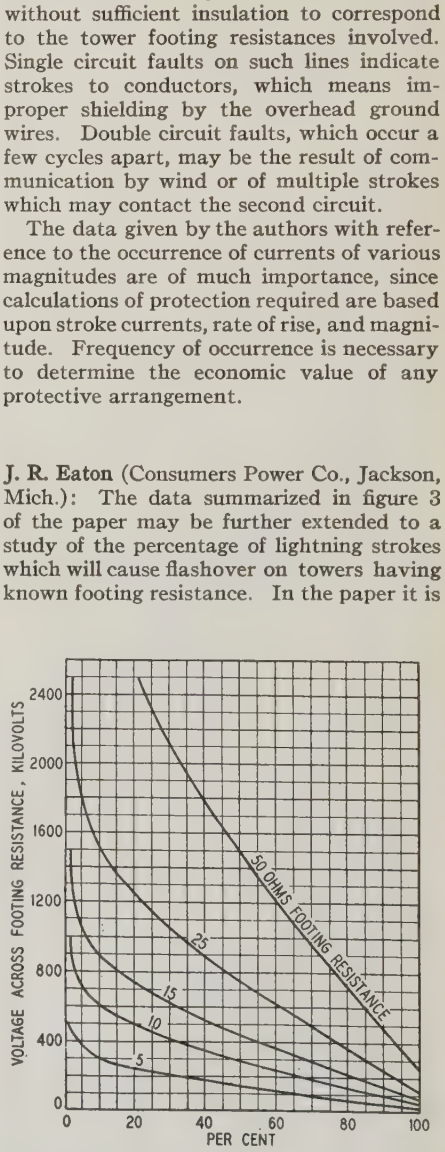
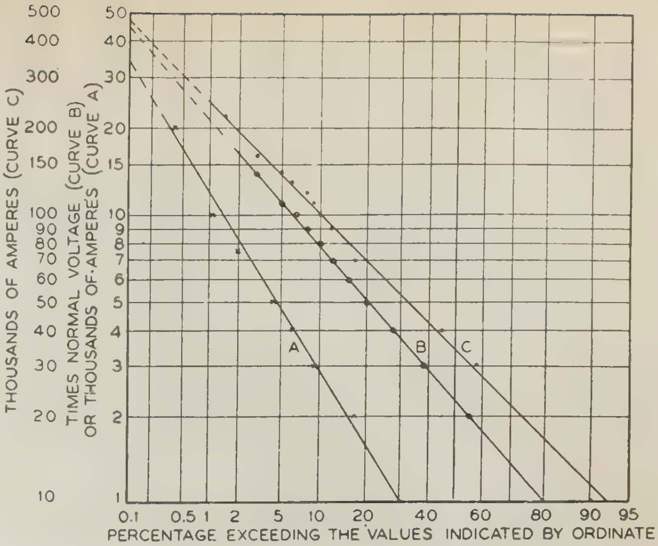


Fig. 1. Percentage of lightning strokes causing voltage across tower footing resistance equal to or greater than values given by ordinate

Fig. 3. Cumulative frequency distributions of lightning voltage and currents

Curve A—Lightning discharge current through 24 kv arresters
Curve B—Lightning voltage on transmission lines measured by surge voltage recorder
Curve C—Lightning stroke current measured by surge crest ammeter



shown that when lightning strikes a tower or ground wire, the voltage across the insulators will be equal to the product of the tower current times the tower footing resistance. A study of line operation shows that if this product exceeds the insulation strength of the line, invariably an insulator flashover will have accompanied the tower current registration. In this way it has been fairly well demonstrated that in the case of a lightning stroke to the ground wire or tower, flashover on the insulator string is determined by the voltage occurring across the tower footing resistance.

Using the data of figure 3 and assuming various values of tower footing resistance, it is possible to calculate the percentage of lightning strokes producing across the tower footing resistance a voltage value exceeding certain specified values. In this way a family of curves may be obtained for each value of tower footing resistance as shown in figure 1 of this discussion. From the curves of figure 1 it is possible to plot another family of curves shown in figure 2 of this discussion. These curves show the effect of footing resistance of the per cent of lightning strokes causing flashover for various line insulation levels, and as might be expected, these curves show that, as the insulation of a line is increased, the importance of low tower footing resistance diminishes. Furthermore, lines having low insulation will receive relatively little benefit from a ground wire unless tower footing resistance is reduced to a very low value. The shape of these curves makes possibe the determination of the value of ground resistance where further reduction of resistance will result in a relatively small improvement in the line performance. For instance, in considering the 1,000 kv level, the curves indicate that with a tower footing resistance of 20 ohms, about 20 per cent of the lightning strokes will cause insulation flashover; at 15 ohms tower footing resistance, 6 per cent will cause flashover; and at 10 ohms resistance, 2 per cent will cause flashover. In locations where footing resistance is normally high and reduction of the

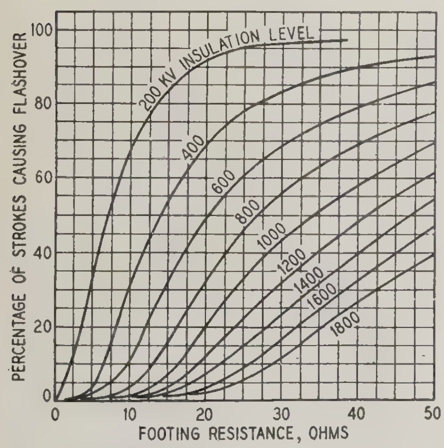


Fig. 2. Effect of tower footing resistance on percentage of lightning strokes causing flashover

resistance can be effected only by considerable expense, the cost of reducing footing resistance from 15 to 10 ohms might not be justified by the small percentage improvement in line operation, especially when consideration is given to the fact that on most lines a certain per cent of lightning strokes will contact the line conductor and result in flashover with no protection being afforded by the ground wire. Considering the interruptions that will occur on a line due to all causes, whether the result of lightning or otherwise, it is obvious that reduction of tower footing resistance below 10 ohms in most cases could not be justified, and on the average lines 15 or 20 ohms might be most economical.

The curves mentioned in this discussion, of course, are entirely dependent upon the accuracy of the original curve shown in figure 3 of the paper. Although at the present time this must be considered an approximation, with continued collection of data with regard to lightning strokes and with corrections which will be obtained, these curves will have much more significance.

S. M. Zubair (Buffalo, Niagara & Eastern Power Corp., Buffalo, N. Y.): The simplicity with which the authors explain the phenomenon of lightning flashovers on transmission lines primarily on the basis of currents and resistances is fascinating. Although the concept of a lightning stroke originating from the earth and terminating on the cloud appears contrary to the general impression, the conclusion seems unavoidable from the pictorial records of lightning flashes obtained with the Boys camera and also from the magnitude and direction of lightning discharge currents through the tower, measured by the surge crest ammeter.

It is quite evident from the paper that this new conception of the direction of the lightning stroke does not necessitate any changes in the basic design principles that have become well established, such as properly placed overhead ground wires and low tower footing resistance, or the counterpoise.

Although the operating records have already demonstrated the effectiveness of these design features, the economic justification for any of these features, however, depends considerably upon the valuation placed on the disturbances and also upon the quantitative determination of the degree of benefits to be derived from each of these features. The former evidently depends upon the type of load and the nature of the community served, but the latter requires a fairly accurate knowledge of the magnitude and frequency of lightning strokes that are likely to affect the transmission lines.

The authors have again made a valuable contribution in presenting such data, this time in terms of magnitude and frequency of stroke current. It is interesting to compare their latest data with those relating to magnitude and frequency of lightning surge voltage recorded on transmission lines which they have presented before. This comparison is made in figure 3 of this discussion, where the magnitude and frequency of lightning arrester discharge currents obtained on the 24 kv wood pole lines of the Detroit Edison system is also shown.

These data, plotted on logarithmic probability paper, seem to show that they all follow some definite law of probability. The exact equation representing these curves has not yet been determined and therefore its full significance cannot be discussed. However, if these straight lines are extended,

Table I—Summary of Faulted Towers and Footing Resistance

Victoria Falls and Transvaal Power Company's 132 Kv Lines, 1926–33, Inclusive

Tower Footing Resistance, Ohms	Total Number of Towers	Number of Faulted Towers: Single Circuit	Double Circuit	Total
0– 5	87	7	0	7
5–10	86	14	3	17
10–15	64	3	6	9
15–20	49	12	6	18
20–25	23	5	4	9
25–30	16	2	5	7
30–35	9	4	4	8
35–40	8	2	3	5
40–45	2	0	0	0
45–50	3	3	0	3
50–55	1	0	1	1
55–60	1	1	0	1
60–65	0			
65–70	0			
70–75	2	2	0	2
Totals	351	55	32	87

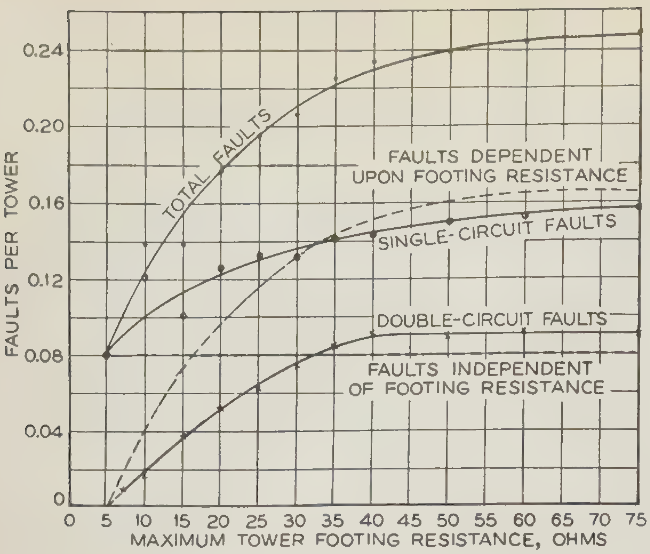


Fig. 4. Lightning flashover record, 1927–33, inclusive

Victoria Falls and Transvaal Power Company 132 kv lines

they would seem to suggest that extremely high lightning voltages and currents may be expected but that they will be of extremely rare occurrence. For instance, about one stroke in a thousand affecting a transmission line may have a current as high as 470,000 amperes or produce 45 times normal voltage on the line.

Since the authors have referred to the performance record of the Victoria Falls and Transvaal Power Company's 132 kv lines, it may not be out of place to make some comments on the analysis of the lightning fault characteristics of this line.

The experience on the South African system led Rendall and Gaff to suggest that single circuit faults are most probably caused by direct strokes to the power conductor, while double circuit faults were caused by direct strokes to the tower or ground wire. If these simple deductions were valid, the shielding effect of overhead ground wires on double circuit lines could at once be estimated by determining the relative numbers of single circuit and double circuit faults. However, a closer analysis of the data, particularly in the light of some American experiences, seems to necessitate some modification in their general conclusion.

Table I of this discussion gives a summary of the flashover data on the South African system and the corresponding data for the Wallenpaupack-Siegfried 220 kv line and the Glenlyn-Roanoke 132 kv line are given in tables II and III of this discussion respectively. When the ratio of flashed towers to total number of towers in each resistance range is plotted against the maximum footing resistance (a given value or lower) the resulting curves, figures 4, 5, and 6 of this discussion, are fairly smooth. Figure 4 shows that the curve representing single circuit faults might be resolved into 2 components, one independent of tower footing resistance, represented by a horizontal line, and the other a curve passing through the origin and very similar to the one representing double circuit faults. If the frequency of flashover caused by a stroke to a power conductor is supposed to be independent of tower footing resistance as suggested by curve *B* of figure 3 of this discussion, and since the voltage across the insulator due to a stroke to the ground wire is generally recognized to depend a great deal upon the footing resistance, it seems to follow that on the South African system double circuit faults probably were caused by a stroke to the ground wire while single circuit faults were caused by a stroke to either the power conductor or the ground wire. The shielding factor of the overhead ground wire is, therefore, higher than a simple comparison of total double circuit and single circuit faults would suggest.

If the horizontal line in figure 2 is assumed to represent the proportion of faults caused by strokes to power conductors, it follows that of all the lightning strokes resulting in faults, 28 (0.08 times the total number of towers) terminated on the power conductors. Assuming that each fault was caused by a single stroke, the total number of strokes would be equal to the total number of faults, which is 87 in this case. If shielding factor be defined as the ratio of the number of strokes terminating on the ground wire or the tower to the total number of strokes (making 100 per cent shielding represented by unity), the average shielding effect of the overhead ground wires on this transmission line during the entire period would be $\frac{87-28}{87} = 0.68$.

In the case of the Glenlyn-Roanoke line, however, the curve representing double circuit faults also seems to have a component which is independent of tower footing resistance, and if the foregoing analysis is valid it would seem that some double circuit

Table II—Summary of Flashed Towers and Footing Resistance

Glenlyn-Roanoke 132 Kv Line, 1927–33, Inclusive

Tower Footing Resistance, Ohms	Total Number of Towers	Number of Faulted Towers: Single Circuit	Double Circuit	Total
0– 5	26	3	1	4
5– 10	52	12	3	15
10– 20	77	21	5	26
20– 30	34	14	4	18
30– 40	19	10	4	14
40– 50	11	7	2	9
50– 60	12	6	6	12
60– 70	5	6	2	8
70– 80	4	2	2	4
80–100	6	3	2	5
100–150	11	13	5	18
150–200	8	7	6	13
Over 200	5	6	1	7
Totals	270	110	43	153

Fig. 5. Lightning flashover record, 1927–33, inclusive

Glenlyn-Roanoke 132 kv line

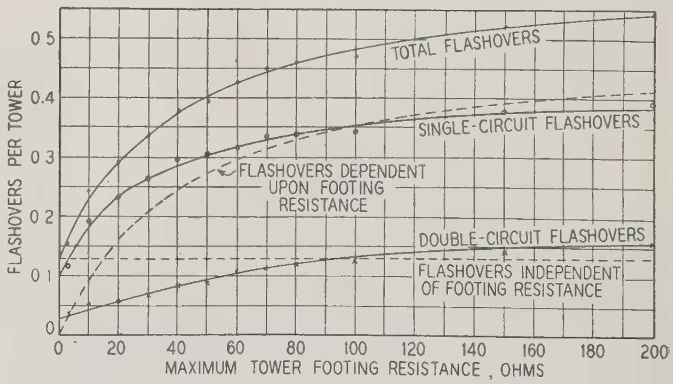
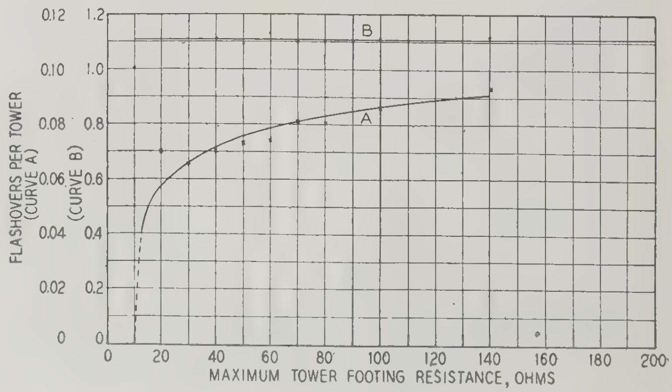


Fig. 6. Lightning flashover record, 1929–33, inclusive

Wallenpaupack-Siegfried 220 kv line

Curve A—Section with overhead ground wire

Curve B—Section without overhead ground wire



faults are also caused by strokes to the power conductor. The average shielding factor calculated as before would be

$$\frac{153 - 0.13 \times 270}{153} = 0.77.$$

No data for tower footing resistance is available for the New York Power and Light

Table III—Summary of Flashed Towers and Footing Resistance

Wallenpaupack-Siegfried 220 Kv Line, 1929–33, Inclusive

Tower Footing Resistance, Ohms	Section With Ground Wire: Total Number of Towers	Section With Ground Wire: Number of Flashed Towers	Section Without Ground Wire: Total Number of Towers	Section Without Ground Wire: Number of Flashed Towers
0– 10	31	0	14	14
10– 20	40	5	50	57
20– 30	22	1	34	44
30– 40	22	2	24	20
40– 50	9	1	16	16
50– 60	11	1	9	10
60– 70	1	1	2	3
70– 80	2	0	2	3
80–100	1	1	11	13
100–150	1	1	2	4
Over 150	0	0	7	8
Totals	140	13	171	192
Ratio	9.28 per 100 towers		112 per 100 towers	

system and therefore, the shielding factor cannot be determined quantitatively in the manner outlined above. However, as Lewis and Foust point out, the relative preponderance of double circuit faults on the New York Power and Light system and the extreme vulnerability of the top conductor on the South African system indicate that these lines are not quite so well shielded as those of the New York Power and Light system.

W. W. Lewis and **C. M. Foust:** The authors are very pleased with the great amount of helpful material included in the discussions on their paper.

C. L. Fortescue's comments concerning the wave front of the current in the lightning stroke are interesting, but none of our data indicate currents rising faster than that described in the second paragraph under case I in the paper. As this was a case where an oscillogram was obtained at a point within a few hundred feet of a lightning stroke to the line, we feel justified in basing our general conclusions on this record.

C. S. Sprague has inquired concerning the tower footing resistance values used in calculating tower potentials, as he presumes these values were obtained from low current measurements and are of questionable merit when used with the high currents obtained under lightning surge conditions. K. B. McEachron investigated this matter some years ago and found that the impedance obtained under surge conditions averaged about $^3/_4$ of the ordinary low current resistance values.

In addition to the discussion material presented by these contributors, the valuable comments and additional analyses of Philip Sporn, K. B. McEachron, J. R. Eaton, and S. M. Zubair are greatly appreciated.

Firing Time of an Igniter Type of Tube

Discussion and authors' closure of a paper by W. G. Dow and W. H. Powers published in the September 1935 issue, pages 942–9, and presented for oral discussion at the electronic tube theory and practice session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

W. E. Berkey (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In this interesting paper the authors have investigated the variation of time lag in igniter firing under surge breakdown for different voltage gradients in an old style igniter type of tube. It is to be regretted that no mention was made of the basic work, in which the firing mechanism was first proposed ("A New Method for Initiating the Cathode of an Arc," J. Slepian and L. R. Ludwig, A.I.E.E. TRANS., v. 52, June 1933, p. 693–8). In this early paper the firing time was briefly discussed and a curve was presented showing how the average firing time varied with the voltage across the starter. During the experimental work performed in 1932 a study was made of the variation in time lag of ignition electrode breakdown, and the result is presented in figure 1 of this discussion. This curve was plotted from a total of 71 observations with the rotating film cathode ray oscillograph and is added evidence of the statistical nature of time lag in ignition electrode breakdown as analyzed by the authors. The igniter used was of resistance material $^1/_8$ inch in diameter and $^1/_2$ inch in length above the mercury. The rod voltage was 150 volts per centimeter and the capacity was 257 microfarads, giving the discharge circuit a time constant of about 6,500 microseconds. The actual voltage fall in one test as measured from cathode ray oscillograms was 13 volts in 632 microseconds. As the capacitor voltage was fairly close to the critical ignition rod voltage, it is quite possible that the few volts drop in capacitor voltage may have increased the time lag and caused the curve to slope off toward the horizontal at longer time lags.

The distribution curves of firing time versus the voltage gradients for a particular

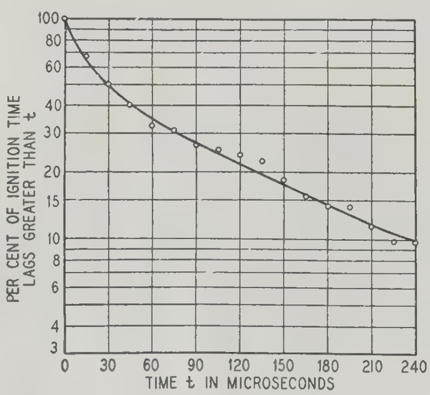


Fig. 1. Frequency of occurrence of a given time lag in resistor material igniter

71 observations; 150 volts ± 7 per cent on igniter

tube have been presented by Dow and Powers. Their data were taken for a momentary condition of the tube. One may ask if the distribution curve is constant in steady operation of the tube or are there continually changing distribution curves. If the distribution curves are changing, then in any selected short time interval there may be a small mean firing time and in another later equal interval a longer mean firing time. Recent data taken by L. T. Bourland on boron carbide igniters on a-c operation indicate a purely random occurrence of starting peaks in excess of 110 volts. The data in figure 2 of this discussion were taken by counting the frequency of peaks exceeding 110 volts on a starter

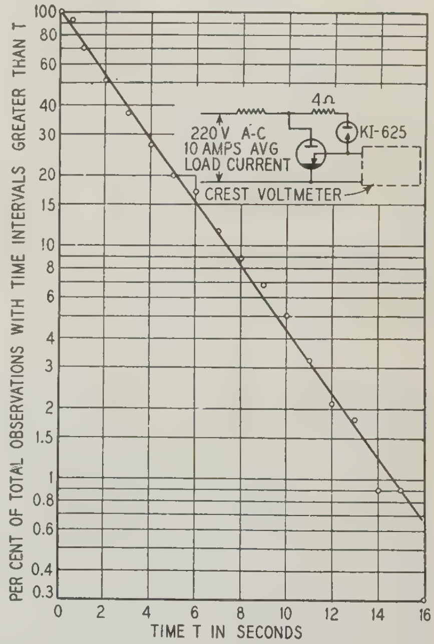


Fig. 2. Occurrence of voltage drops in excess of 110 volts on ignition electrode with a-c operation

340 observations

under stabilized continuous 60 cycle operation and plotting the frequency of occurrence against the time interval between such peaks. It was found that the time intervals between peaks exceeding 110 volts was such as to indicate that the occurrence of these peaks was purely random and, therefore, a change of the distribution of firing times did not occur during the time of this test because if it had, a preference for some intervals in figure 2 would have been found. There were more than 300,000 operations during this run and 340 of them were in excess of 110 volts.

Following the original development of the igniter type of tube, considerable work has been done on materials and shapes of starters to give low voltage consistent operation. Figure 3 of this discussion shows an oscillogram of a typical low voltage starter particularly adapted for low voltage a-c operation.

In practical operation on capacitor impulse starting, it is necessary only to increase the voltage gradient on the igniter rod to reduce the flicker to a very rare occurrence.

Our data fail to show any evidence of

mercury agitation causing the observed variation in time lags. To check this theory, a starter was made from a resistance material, commercially used in heating elements, and partly buried in solder. This solder cathode with the igniter, when placed in an evacuated vessel, gave variations in firing time similar to those obtained with mercury cathodes. Eight observations of the time lag gave variations of from a few microseconds to complete failure to ignite and indicated a random characteristic.

W. G. Dow and **W. H. Powers:** W. E. Berkey's very helpful discussion raises a question as to the constancy of the mean firing time during a series of observations, then introduces a set of data to indicate that the mean firing time is substantially constant over a considerable period. The authors of the paper attempted to obtain a partial check in this respect by taking the observations in irregular order; for example, of the 10 observations at 164 volts per centimeter (figure 7), 4 were taken on film 86 and 6 later on film 87; comparison of the results showed similar behavior. The 120 and 197 volts per centimeter observations were similarly split and subsequently compared. Thus there seemed to be no progressive change in mean firing time during the series of observations leading up to figure 7. Berkey's results, as reported in figure 2 of his discussion, are very interesting in that they provide a much more complete check in regard to constancy of mean firing time.

The oscillogram in figure 3 of the discussion, showing ignition occurring in the neighborhood of 50 volts, is an interesting contrast with the minimum of about 200 volts for the older tube used in securing the data for the paper.

The observations reported by Berkey on an igniter buried in solder rather than immersed in mercury indicate that variability in mean firing time cannot be attributed to microscopic variations in mercury level; this appears to be the answer to the question raised in the last paragraph of the paper. This answer is in accord with the authors' expectations, based on indirect evidence, and it is very satisfying to have the direct evidence presented.

It is unfortunate, as Berkey suggests, that the original paper by Slepian and Ludwig was not included in the bibliography and referred to in the text of the paper as it forecasts in a general way the type of results to be expected from the study of firing time only.

It has seemed to the authors that the most interesting and important result of the whole series of tests is the simple information, conveyed in figure 4, parts *G* and *H* and in others not presented, that no time is consumed in the transfer of the arc from the igniter rod to the anode; this has not been generally recognized heretofore.

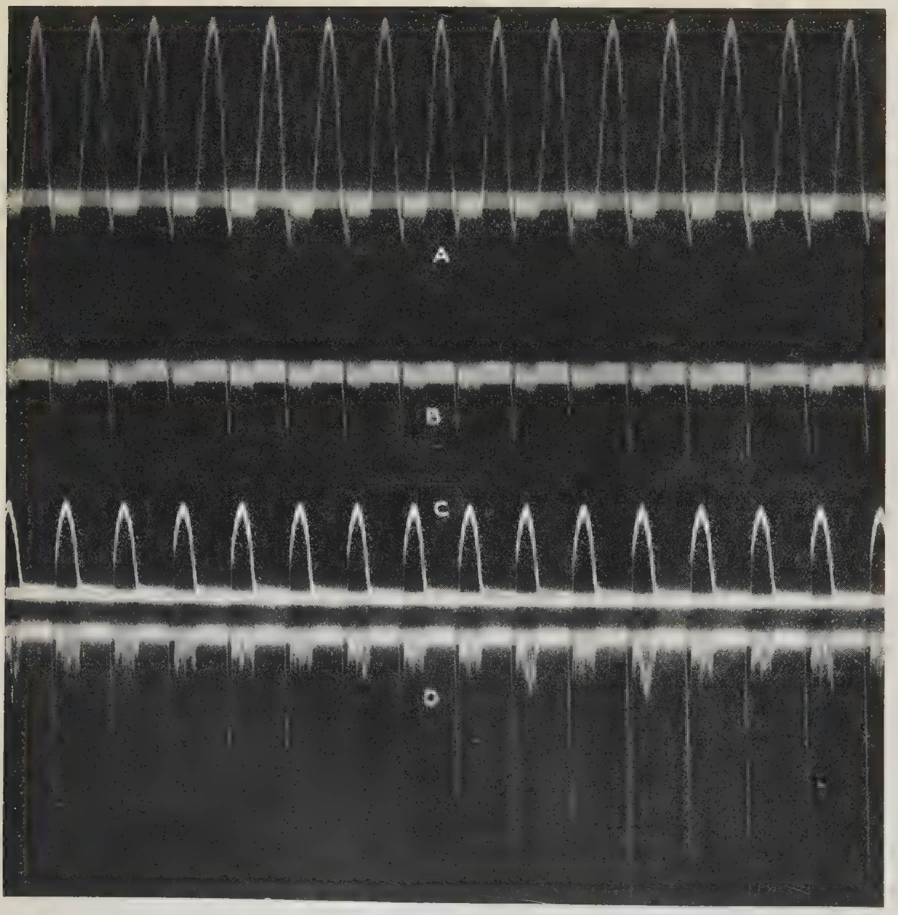


Fig. 3. Oscillograms of current and voltage in a typical igniter for low voltage a-c operation

A—Anode volts, scale 116 volts per centimeter; B—Starter volts, scale 52.4 volts per centimeter; C—Anode current, scale 1.8 amperes per centimeter; D—Starter current, scale 2.75 amperes per centimeter

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Analysis of Rectifier Filter Circuits

Discussion and author's closure of a paper by M. B. Stout published in the September 1935 issue, pages 977–84, and presented for oral discussion at the electronic tube theory and practice session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

C. S. Roys (Purdue University, West Lafayette, Ind.): In view of the many recent developments that require rectified alternating current, together with the added possibility of d-c transmission, this paper is especially appropriate at this time. By treating the problem as one of recurrent transients, a radical departure from the usual Taylor's series method, the author is thus able directly to determine exact oscillograms which are then analyzed for subsequent operations. This should prove to be a decided advantage in many applications where the actual behavior at the discontinuities is desired.

Another phase of the same general problem which is of little consequence in connection with low voltage power supplies, but which is of the greatest importance in d-c transmission and surge generator studies, is the response of rectifying circuits under transient conditions. In this regard, it is to be regretted that no feasible solution has as yet been developed, so far as can be learned from the literature. One obvious method that has been proposed and which can be easily formulated in a general sort of way involves that form of the superposition theorem commonly known as Duhamel's integral. Unfortunately, however, this results in a nonlinear integral equation of a most formidable nature which apparently can be solved in only an approximate sort of way and even then only with a considerable amount of difficulty. Furthermore, it has an added disadvantage in that there is no suggestion regarding the general form of the solution in terms of a simple combination of well known functions. It would be desirable if the author would extend his method to the transient case by determining the oscillograms cycle by cycle. It is believed that such a procedure would be quite convenient when applied to some of the networks under consideration in his article, although it would prove prohibitively tedious in others.

During several years past I have given this transient problem considerable thought, especially in connection with a study that is being made of the charging characteristics of surge generators. A recognition of the inherent difficulties involved in a step by step, cycle by cycle, or integral equation solution has led to the formulation of an entirely unique method of attack. In brief, this is the counterpart of the Taylor expansion that has been applied by so many investigators to networks under steady state conditions, and consists in the setting up of a series for the plate current of a tube feeding into a network whose

terminal impedance operator is Z_p. The final form of the solution is then obtained by the application of the fundamental laws of operational calculus. A brief discussion of this method is included in an Engineering Experiment Station bulletin now in preparation, but inasmuch as many additional developments have materialized since the completion of the original manuscript, a paper covering this work is now in preparation. It might be appropriate to mention at this time, however, that the characteristic of the tube has finally been expressed in the form of a system of normalized Legendre polynomials, special consideration being given to the so-called "perfect rectifier" problem.

M. B. Stout: I gladly agree with C. S. Roys that much work remains to be done in the study of rectifier circuits under both steady state and transient conditions. It is possible to produce a cycle-by-cycle solution for transient cases by present methods, but in many instances, at least, the operation is decidedly laborious. It may well be that a more compact and convenient solution may be formulated in some radically different manner.

I would like to call attention to an error in equation 2 of the paper. The quantities $R^2 + (2\omega L)^2$ and $R^2 + (n\omega L)^2$ in the denominators of the second and third terms should be shown under square root signs.

A New Carrier-Current Coupling Capacitor

Discussion and author's closure of a paper by E. D. Eby published in the August 1935 issue, pages 848–52, and presented for oral discussion at the power transmission session of the Pacific Coast convention, Seattle, Wash., August 27, 1935.

L. R. Ludwig (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The paper is very interesting and covers a type of equipment for which many applications will be found. The possibility of tapping high voltage lines for local loads was outlined in a short article by H. Brooks (*Elec. Jl.*, v. 26, Oct. 1929, p. 477–8); the lighting of airway beacons direct from high voltage lines was described in a paper by F. W. Cartland (A.I.E.E. Trans., v. 50, Mar. 1931, p. 294–8).

Both the suspension type and pedestal type coupling capacitors described in these references owe their 8 years highly satisfactory performance to the principle of producing very uniform voltage distribution in each coupling capacitor by dividing the insulation into a very large number of series elements so that the normal voltage per step is less than 400 volts, and working each one of these individual capacitor sections at a working stress substantially below standard practice for the same type of capacitor insulation when used on motor circuits. This distribution of voltage eliminates ionization inside, at all points, and produces a uniform electrostatic field over the porcelain. This normal conservative working stress of 100 to 125 volts per thousandth of an inch allows for variations in voltage due to capacity variations and co-ordinates the device with the external flashover so that the insulation is not stressed greatly when the voltage is sufficiently high to flash over the porcelain. Coupling capacitors so designed may be connected to a line without introducing any more hazard than another string of insulators, and the risk is a tangible one which can be measured in terms of wet and dry flashover of the porcelain casings. The performance of over 1,000 coupling capacitor units, some of which have seen 5 years service, demonstrates the soundness of this basis of design.

Based on the information given in this paper, the insulation is not subdivided as much as has been done and the voltage across individual sections is approximately 1,000 volts. Even this does not appear to warrant the use of inert gas unless it is put in because of the fluidity of the liquid at normal temperatures and the danger of trapping air when agitated in handling. This can be avoided by the use of an oil which flows at 37 degrees centigrade and which avoids diffusion of air in handling since it is like vaseline at normal temperatures. This oil also permits the handling and individual testing of each section after treatment and before housing since it does not run off or run out of the section.

Also based on the dimensions given, Eby indicates that the insulation operates normally at about 220 volts per thousandth of an inch, and during flashover the working stresses reach 1,160 volts per mil. This raises a point as to the need of protection or accessory equipment, since the device no longer can be looked upon as a string of insulators, but rather as a piece of apparatus which cannot stand as much stress as the line. However, the coupling capacitors in this case are protected by the arresters which are installed for other reasons.

Over 3 times as much working material is required for the stress of 125 volts per mil as compared with 220 volts per mil.

It is agreed that coupling capacitors should be noninductive on account of their use in connection with carrier current work. However, further elimination of the inductive effect of wound sections may be effected by extending the foil at each end of the section and connecting to all turns. This also gives the coupling capacitors a high current carrying capacity.

The curve given for variation in capacitance with temperature is unusually flat above 10 degrees centigrade which is not typical of oil-paper capacitor insulation and goes down at the lower temperatures which again is not typical. However, the over-all variation is about as to be expected. It has been found quite tedious to make such tests and that 30 or 40 hours are required for each point on the curve due to the high thermal capacity of such large units with their porcelain housing of low thermal conductivity.

E. D. Eby: Any comparison of designs on the basis of relative dielectric stresses must recognize the ability of the respective insulations to withstand successfully the stresses to which they are subjected. In the design of the coupling capacitors described the stresses employed in the dielectric are considerably less than those which have been found satisfactory for this class of insulation after many years of extensive use in capacitors for power factor correction. The notably excellent record of these modern oil-paper power factor correction capacitors attests the dependability of insulation of this kind. Similar capacitors are employed also in the construction of impulse generators which receive far more severe and frequent abuse from overvoltage surges than apparatus in operation on transmission lines. Any implication that these coupling capacitors represent a hazard to the line because of the working stress in the dielectric is quite without foundation.

The proper co-ordination of the internal strength and the external flashover voltage under both normal frequency and impulse conditions is attested further by the demonstrated ability of these capacitors to withstand repeated external flashover without internal distress. The problem of co-ordination of the complete assembly of units for a given system with the line insulation of that system may or may not involve lightning arrester protection, depending on the relative flashover voltages of capacitor and line insulators and upon the operator's desire to prevent capacitor flashover. This problem, however, is quite outside the scope of design of the individual capacitor unit, which is concerned with the relative internal strength and external flashover voltage of the unit.

The use of a larger amount of material in one design than in another for the same service is not necessarily an indication of relative dependability or economy. It is generally recognized that a smaller quantity of more carefully selected material, when properly engineered, may have a dependability equal to or even greater than that of a larger quantity of poorer material less advantageously disposed. Experience has shown that, as a rule, the former practice results also in greater economy than the latter.

In the selection of oil as the impregnation medium for the paper insulation of these capacitors, recognition has been given to its generally accepted superiority over solid compound for devices operating at high voltage. The elimination of void formation with temperature changes permits the safe operation of the oil impregnated paper at higher stresses than could be allowed with safety in compound treated insulation. The ready dissipation of losses from the dielectric is another advantage of oil impregnation. The case is similar to that of oil filled high voltage underground cables which can be operated at twice the stresses allowable in cables of the solid type.

Little comment is needed upon the use of an inert gas in the expansion chamber above the oil, other than to point out that the use of dry gas under pressure is such a convenient means of expelling the surplus oil after filling that no excuse for the use of air remains. As far as any appreciable oxidation effect upon the oil is concerned, there would be no objection to air in the expansion chamber, but since "the best is none too good" and gas under pressure serves a useful purpose in the maufacture it is employed in preference to the admission of air.

It is generally true that the characteristic capacitance-temperature curve of oil-paper insulation is very nearly a straight line of a fairly uniform upward slope at about one

per cent increase for each 25 or 30 degrees of temperature throughout the operating range. The droop at the low temperature end of the published curve resulted from the departure from a straight line curve of the minimum temperature test reading and may be incorrect. If so, the revised curve would be more favorable than the published one. That this low point could not have resulted from too great haste in making the test is evident when it is remembered that had the internal temperature not reached the observed external temperature, the reading would have been higher and the droop of the curve correspondingly less. This seems to have been overlooked in the discussion.

While the points brought out in the discussion have been noted with much interest, nevertheless the absence of any important criticism of the design and performance of these capacitors is highly gratifying to the author of the paper, and he wishes to express his appreciation for the general approval of this design. Figure 7 of the paper is in error in that the right hand scale showing microfarads has been raised one division. The value 0.003 should be shown where the value of 0.0025 now appears, etc.

Engineering Features of the Boulder Dam-Los Angeles Lines

Discussion and author's closure of a paper by E. F. Scattergood published in the May 1935 issue, pages 494–512, and presented for oral discussion at the power transmission session of the Pacific Coast convention, Seattle, Wash., August 27, 1935. This paper was also presented at the summer convention, Ithaca, N. Y., June 28, 1935, and other discussion was published in the February 1936 issue, pages 200–04.

Abe Tilles (University of California, Berkeley): I should like to ask just one question, though it is, perhaps, rather a big one. I think it will be of interest if the basis of choice between 50 cycle and 60 cycle transmission is indicated. What is the comparative cost and efficiency of the iron core machinery involved, i. e., the generators, transformers, and synchronous condensers? Also, what is the power limit of the line at each of these 2 frequencies?

E. F. Scattergood: In answer to Abe Tilles' question, I would state that the basis of choice between 50 and 60 cycles was not due in any way to the relative cost or efficiency of apparatus or transmission.

It was the original intention to operate the system of the Bureau of Power and Light of Los Angeles at 60 cycles, but because of the contemplated purchase of that part of the Southern California Edison Company's 50 cycle distribution system, lying within the city of Los Angeles, and because the bureau would necessarily, for a number of years, purchase a substantial part of its energy from the same company, the frequency was at first established at 50 cycles. However, it has always been the intention eventually to change to 60 cycles and all the equipment has been purchased in the past to operate efficiently at either frequency.

With the advent of the Boulder Canyon development and the possibility of additional developments and interconnections between developments, the bureau considered it advisable and opportune to change the frequency to 60 cycles in keeping with the standard for which all utilization apparatus used in this country is designed.

Steady State Solution of Saturated Circuits

Discussion and author's closure of a paper by Sterling Beckwith published in the July 1935 issue, pages 728–34, and presented for oral discussion at the electrical machinery session of the Pacific Coast convention, Seattle, Wash., August 27, 1935.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In this paper several methods of dealing with saturation in steady state stability problems are presented but this discussion will be limited to the equivalent reactance method. A number of methods of dealing with saturation have been used in the past but in this paper and in a previous paper (reference 1 of the paper) by a new term "equivalent reactance" has been used. This reactance is intended to represent the actual machine with fixed excitation in steady state stability calculations.

Such a reactance may be very useful especially in stability studies on a system where a number of machines are involved. However, there are some problems and limitations which should be clearly pointed out.

In the previous paper referred to an equivalent quadrature axis reactance and equivalent quadrature axis excitation are also introduced when dealing with salient pole machines, which complicates the theory and makes it impractical. Beckwith has avoided this difficulty by using a somewhat more general concept of equivalent reactance which is simpler and more useful.

Using Beckwith's concept, the equivalent reactance might be defined in general as the reactance which, used with a fixed internal voltage, will give the same change in terminal conditions as the actual machine with fixed excitation for a small slow change away from a certain operating point in a given direction.

The definition of such a reactance is complicated by the fact that the reactance varies with the direction of change away from a given point as well as varying for different terminal conditions. For example, if the direction of change is such that constant power is maintained, a typical machine might have an equivalent reactance for a given operating point which is 0.7 of the unsaturated value but if the direction of change is such that constant voltage is maintained, the equivalent reactance might be 0.9 of the unsaturated value for the same operating point.

Since this reactance is intended primarily for use with steady state stability calculations, the assumption that the direction of change is such as to maintain constant power is a good approximation and becomes exact as the pull-out point is reached. The justification of this assumption is mentioned in the paper, but the writer believes that this assumption might well be included as part of the definition.

Table I of the paper illustrates another point which must be understood when using the equivalent reactance. The equivalent reactance determined at the normal operating point cannot be used to calculate pull-out, nor can the reactance determined at pull-out be used with a fixed internal voltage determined at normal conditions, unless the normal operating point is very close to pull-out.

The paper suggests one approximate method of calculating the maximum power by using the average value of equivalent reactance at normal conditions and the estimated value at pull-out. The error shown is not large but in other simple cases calculated in detail this method was shown to give too high a value of maximum power, the error being as high as 10 per cent rather than 2 per cent. Much greater accuracy was obtained by the following method.

If the average value of the equivalent reactance of normal conditions and at an estimated pull-out condition is used to calculate the current and voltage at pull-out the equivalent reactance and the internal voltage calculated for the new terminal conditions may then be used to test for stability. This involves a cut and try process but the writer believes it to be the only practical method so far presented for calculating maximum power using equivalent reactances.

Another point about "equivalent reactance" which may cause some confusion is that it does not, in general, give the true internal angle and it cannot be used to calculate accurately the rate of change of power with respect to angle. However, the criterion of maximum power at the point where the power fails to increase with an increase in angle may still be used, for an increase in real angle produces an increase in equivalent angle although the increment may not be the same magnitude.

The approximate method of test suggested in J. W. Butler's discussion of reference 1 of the paper requires determining the slope of the zero power factor volt-ampere curve for a given excitation at the point corresponding to the same voltage back of leakage reactance as the actual conditions. Potier's reactance should be used instead of leakage as this will greatly increase the accuracy especially for salient pole machines. It is better to use the direct axis projection of the voltage back of Potier's reactance as Beckwith suggests.

The other approximate method mentioned involves the determination of the ratio of the slope of the no-load saturation curve to the air gap line S. The equivalent reactance is then approximately $X_{eq} = X_p + S(X_d - X_p)$. Here again it is more accurate to use Potier's reactance X_p rather than armature leakage, and the point at which the slope should be measured is best determined by the direct axis projection of the voltage back of Potier's reactance. If Potier's reactance is constant, these 2 methods can be shown to be identical and even if Potier's reactance varies appreciably, the difference in results is small.

C. C. Shutt (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In the published discussion (Elec. Engg., v. 53, Mar. 1934, p. 484–8, and Apr. 1934, p. 603–07) of reference 1 of this paper several simpler methods were proposed for the determination of the reactance. The purpose of this discussion is to compare the results obtained in the calculation of the equivalent reactance by 3 of these methods and by the method in this paper. The calculations are made for 200-horsepower 450-rpm 100 per cent power factor motor. The test short circuit ratio is 1.02. A complete set of tested zero power factor curves was available as shown in figure 1 of this discussion. The various methods used are:

1. No-load and zero power factor saturation curve method referred to by R. D. Evans as one which has been used in steady state stability work for a number of years. The difference between the zero power factor rated current saturation curve and the no-load saturation curve is 287 volts (line to line basis) or 65.2 per cent at the rated field current.

2. A method based on a modification of that suggested by Sterling Beckwith in his discussion of the previous paper. The equivalent reactance is given by the expression

$$X_{eq} = X_p + (X_d - X_p)\frac{S_1}{S_2}$$

Where

X_p = Potier reactance

X_d = direct axis unsaturated synchronous reactance

S_1 = slope of no load saturation curve at the voltage corresponding to direct axis projection of voltage back of Potier reactance at full load

S_2 = slope of air gap line

3. The method proposed by J. W. Butler. It requires finding the slope of the zero power factor volt-ampere curve at a voltage which gives the same flux conditions as rated load. However, the

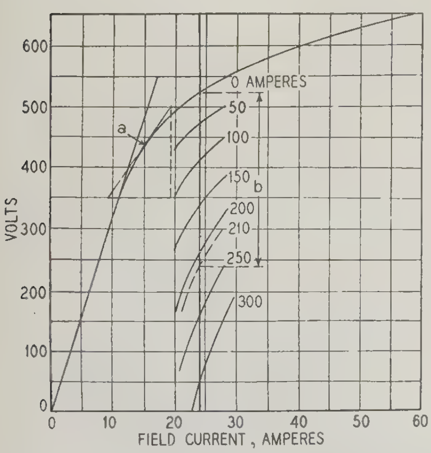

Fig. 1. Zero power factor saturation curves

a. Slope of no-load curve at a voltage equal to the direct axis projection of the voltage back of Potier reactance, method 2

b. Reactance volts, method 1

Potier reactance is used in place of leakage reactance and the internal voltage is that back of Potier's reactance in the direct axis.

4. The method suggested by Beckwith in the present paper as equivalent reactance from vector diagrams. This method was used to calculate the reactance of 3 different conditions. These are:

a. Constant power with variable terminal voltage

b. Constant terminal voltage with variable power

c. Constant power factor with variable terminal voltage

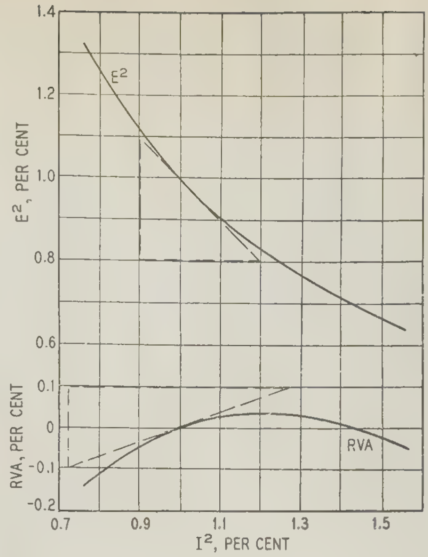

Fig. 2. Curves of voltage squared and reactive volt-amperes versus current squared

$X_{eq} = -0.37 + \sqrt{0.14 - (-1.00)} = 0.70$

The excitation is held constant at the value for full-load unity power factor. The reactance given is taken from the slopes of the curves at rated voltage and current. The condition of 4*a* may be found where synchronous motors are driving pumps or other constant loads. The reactance found in 4*b* could be used in any problem where the motor was connected to a constant voltage and drove a load which slowly changed in magnitude. The reactance of condition 4*c* would be applicable to the usual synchronous motor ship propulsion installation. Another case for which the reactance could be determined would be for constant reactive current. With a unity power factor machine this becomes identical with 4*c*. Another type of reactance would be for constant current. This could not be solved with the equation in its present form. The curves for the solution of case 4*a* are shown in figure 2 of this discussion.

The reactance values obtained by the different methods are:

Method...	1	2	3	4*a*	4*b*	4*c*	X_d
X_{eq}, Per Cent....	67.0	70.0	71.6	70.0	74.5	90.8	120.0

The first 3 methods really depend upon zero power factor tests and should give comparable results. Since a motor with fixed excitation and constant power has variation in the direct axis current only, the results obtained by the fourth method for this condition check with the results obtained by the more approximate methods. For conditions 4*b* and 4*c* results of the first 3 methods no longer check with the more accurate results obtained by method 4. For such conditions it would be desirable to have data from load tests available in order to plot the curves required for method 4.

Sterling Beckwith: L. A. Kilgore has suggested that the reactance defined as equivalent reactance might well be restricted to the reactance applying for a constant power condition. This appears to be a good suggestion, as it would still be possible to identify any other equivalent reactance by a single phrase as "equivalent reactance for constant voltage conditions" or "equivalent reactance for variable power changes."

Table I of the paper was calculated for the actual system being studied at the time. This system was to be operated normally much closer to the steady state limit than most systems are, and consequently Kilgore's observation that greater errors than those shown could result from using the same methods on other systems is quite correct.

Both calculations and tests recently made confirm his statement that Potier reactance rather than leakage reactance should be used to determine internal voltage, especially in using J. W. Butler's approximation $X_{eq} = X_p + S(X_d - X_p)$.

C. C. Shutt's example is very interesting. I believe, however, that the agreement found between methods 1, 2, 3, and 4*a* may not be as close for all machines as for the one chosen. For example, if the motor of figure 1 had been rated as 480 volts, 95 per cent lagging power factor, and 16 amperes field current, the reactance by method 1 would have been about 78 per cent and by method 2 about 60 per cent. Also, as pull-out is approached, and terminal voltage drops with increasing load, the current variation in case 4*a* will not be entirely in the direct axis, and the reactance of case 4*a* will more nearly approach that of case 4*c*. In general, however, as shown by Shutt's illustration, the approximate methods are very useful for normal machines in any but the most particular cases.

Tests on Armature Resistance of Synchronous Machines

Discussion and author's closure of a paper by B. L. Robertson published in the July 1935 issue, pages 705–9, and presented for oral discussion at the electrical machinery session of the Pacific Coast convention, Seattle, Wash., August 27, 1935.

T. A. Rogers (University of California, Berkeley): The author discusses the relative advantages and disadvantages of 4 methods for determining the armature resistance of a machine from terminal test data taken under conditions of no load. It has been the usual procedure in the past to determine the losses at no load and to assume that they hold under conditions of load. This appears to be a reasonable assumption from the results of this paper in so far as machine performance calculations are concerned. The test methods proposed are simple of application and in general may be applied to machines already installed.

Test information on the effective resistance of an armature winding is very meager, the resistance usually being neglected in all machine calculations except that of efficiency. The tabular results of machine performance given in this paper indicate the accuracy obtainable when resistance is included in the vector diagram for the unsaturated machine. Additional data have been taken by the author to indicate that similar accuracy may be had in the calculation of the steady state power angle curves for the saturated machine. The effect of

armature resistance and of saturation upon the various reactances were included in these calculations.

Because the results of this paper find their greatest application in machine calculations by way of the vector diagram, no attempt is made in the test methods to split the losses into their various components. All losses that vary approximately as the square of the current are lumped together and termed the effective resistance loss. This grouping of losses is of course ideal for work with the vector diagram where provision is made only for a reactance drop. Little use may be made of the effective resistance losses by designers except in checking the total calculated losses and in determining the over-all efficiency of the machine.

W. G. Hoover (Stanford University, Calif.): In discussing the methods by which the effective armature resistance may be obtained, the author states that the use of the V-curve is to be recommended as a practical method. It is not explained just how this test is to be carried out to obtain the results indicated by the curves shown.

Figure 1 of this discussion shows results of V-curve tests made upon a 15 kva synchronous machine at Stanford University. It is evident that there is a considerable difference in the curves for over-excitation and for under-excitation. For a constant terminal voltage, over-excitation produces a small increase in loss that should be chargeable to the armature iron loss. Likewise, under-excitation causes that part of the total input consumed as iron loss to decrease somewhat. These effects may be explained in an approximate manner as due to changes in the air-gap flux permitted by the leakage reactance. Though the difference in the 2 curves should not be more than a few per cent for any machine, it is important in comparison with the variation of resistance loss values determined by different methods. This discussion applies equally well to the dynamometer method explained by the author.

It would seem that a very desirable value of resistance or resistance loss should be obtained by drawing an average curve between the results of tests with over-excitation and with under-excitation. This average is quite allowable because of the closeness of the 2 curves.

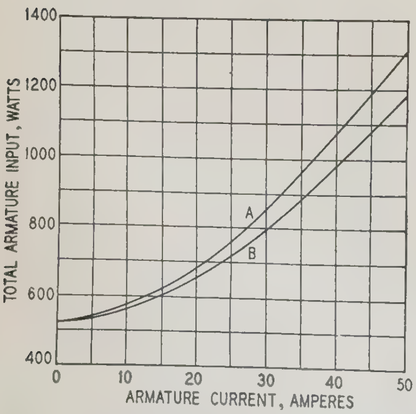

Fig. 1. No load V-curve test of a synchronous machine with terminal voltage constant and separately driven exciter

A—Over-excitation
B—Under-excitation

B. L. Robertson: W. G. Hoover reports a case in which results for armature resistance for over-excitation and under-excitation are not the same, and more recently another instance of this has been reported on a machine in our own laboratories. It would seem that at least some slight variation between the 2 resistance runs might be expected because of the change in air gap flux under such widely different conditions of excitation. While taking the data shown in the paper, and while obtaining similar data on other machines, these differences were sought but did not appear. What exact reasons there may be for variations among machines are not recognized, all tests apparently having been made in the same manner. As Hoover suggests, it would seem desirable and proper to average the results when differences do appear.

Test Values of Armature Leakage Reactance

Discussion of a paper by T. A. Rogers published in the July 1935 issue, pages 700–05, and presented for oral discussion at the electrical machinery session of the Pacific Coast convention, Seattle, Wash., August 27, 1935.

B. L. Robertson (University of California, Berkeley): Within recent years both the author and I have had occasion to determine as accurately as possible the armature leakage reactance of several synchronous machines with the view to the use of this quantity in studies involving saturation of those machines. The only way open seemed to be by calculation, employing the formulas of P. L. Alger and L. A. Kilgore. Out of interest, however, and for a rather complete comparison of calculated values of armature leakage reactance for the machines considered, computations also were carried out for many other published formulas. The results of the calculations for 2 of the machines are given here in per unit notation:

Formula	Machine 1	Machine 2
Fechheimer (1912)	0.1022	0.107
Arnold (1913)	0.0668	0.0646
Lawrence (1916)	0.0719	0.0666
Doherty and Shirley (1918)	0.194	0.1685
Gray (1926)	0.143	0.172
Alger (1928)	0.0837	0.0861
Kuhlmann (1930)	0.0966	0.1036
Kilgore (1931)	0.0775	0.0824
Still (1932)	0.0506	0.0732

This tabulation shows variations in calculated values of armature leakage reactance nearly as great as 4 to 1, although the method of Doherty and Shirley is admittedly too high. The wide differences among the results indicate that many of the formulas cannot be so reliable. Certainly, to one approaching the calculation of this quantity, unacquainted with the theory behind the manners of arriving at certain of the formulas, these various results would be a trifle bewildering. Apparently, as might be indicated in the paper "Armature Leakage Reactance of Synchronous Machines" by L. A. March and S. B. Crary (ELEC. ENGG., April 1935, p. 378–81) and now by Rogers, the generally accepted developments of Alger and Kilgore lead to better figures. This is the conclusion which I have received from many calculations and comparisons of leakage reactance expressions. Not all of the formulas are consistent with present definitions of this reactance, nor do all include the major accepted components.

It always has been desired that armature leakage reactance be obtained by test, but because this quantity is not open to direct measurement through a knowledge of terminal readings its value for any machine has never been definitely established in such manner. It has been approached, however, by way of a compromise between test and calculation. The methods which have seemed of value are those by Schenkel (with variations by Roth), and March and Crary. In the first instance the calculated or measured effect of the bore flux is subtracted from the result found with rotor removed. In the second case armature leakage reactance is approached as the limit of Potier reactance obtained under conditions of extremely high saturation, but it should be noted that the calculated reactance which is approached is *assumed* to be the *true* armature leakage reactance. The test verification of armature leakage reactance through addition of the calculated armature leakage reactance and the reactance of armature reaction to give synchronous reactance (this last accurately determinable by test) is open to an objection in that it is possible for one calculated quantity to be too low by a given amount and the other to be too high by exactly the same amount, the 2 errors nullifying each other in the sum.

I believe that it might be concluded that theoretically the most accurate means of experimentally determining armature leakage reactance is the air core method employing the test coil to measure the bore flux. However, removal of the rotor for insertion of the test coil makes this test very difficult, if not impossible, of accomplishment. Furthermore, it will in no way allow of knowledge on the influence of saturation because of the low voltages which are required. The simplest method is the modification of the zero power factor load vector diagram, but here again a test coil in necessary, and on machines with long shafts may be very hard to place. Commercially, it is to be doubted if test methods will be used rather than calculations, although for detailed theoretical laboratory investigations experimental checks on calculations should be carried out.

It is of interest to note that the many suggestions aiming at test evaluation of armature leakage reactance involve widely different methods of approach. The reason, of course, is obvious, because a quantity directly obtainable through instrument readings alone usually is found only by one or 2 methods, and these generally related. I think that the work accompanying the present paper is of considerable value in comparing the results of these various tests

on specific machines, and in bringing together the many test procedures pointing toward the same goal. The nearness of the results to each other, and to accepted formulas for calculation of armature leakage reactance, go far to substantiate these reactance expressions, and add greatly to the confidence which may be placed in them when used for machines differing widely in design.

Time-Temperatures Tests to Determine Machine Losses

Discussion and author's closure of a paper by M. D. Ross published in the May 1935 issue, pages 512–15, and presented for oral discussion at the electrical machinery session of the Pacific Coast convention, Seattle, Wash., August 27, 1935. This paper was also presented at the summer convention, Ithaca, N. Y., June 26, 1935, and other discussion was published in the October 1935 issue, pages 1107–09.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents a method of measuring the loss density in the various parts of electrical machines by the use of time-temperature curves. It is of great advantage to the designer of electrical machines to know the distribution of the loss as well as the total losses, for this enables him to check methods of calculation and to prove the effectiveness of certain features which are intended to reduce the losses.

There are some practical limitations of this method of test which should be kept in mind. The loss density is theoretically determined from the specific heat and the slope of the temperature-time curve. With practical methods of measurement, readings during several minutes must be used and a curve drawn through a number of test points. Within this time the slope of the curve may be affected slightly by heat flowing to adjacent bodies or by heat flowing in from other hot bodies. In the paper it is suggested that these effects be accounted for by making an empirical correction to the specific heat, which would be determined by tests under known conditions.

The mutual effects of another body and source of heat may be approximated theoretically by assuming 2 thermal capacities connected by a thermal resistance and with a thermal resistance connecting one body to a point of known temperature which represents the ambient air or cooling medium. The differential equations may be set up for this case and the solutions give 2 exponential terms for the temperature curve of each body. The initial slope at zero time may be shown to be only a function of the change in rate of loss and the specific heat as stated in the paper, but by drawing the complete calculated curve, the effect on the slope during the first few minutes may be studied.

An analysis of this type was used to explain the difference between the apparent and the actual specific heat in the ring sample test described in the paper. The method using the thermal capacity of both bodies is too complicated for general use in loss studies but may be used as a check on the limitations of the similar method.

T. A. Rogers (University of California, Berkeley): The method of determining stator losses proposed by the author is quite ingenious in that it is possible to separate the losses into their various components by means of a series of heat runs. His time-temperature tests appear to have been devised to aid the designer in determining average loss coefficients and a more efficient arrangement of the end turn windings. There is no indication that results suitable for use in the machine diagram were considered. I would like to ask the author if an attempt was made to arrive at a value for the effective resistance of the machines tested and if the results obtained were similar to those shown by B. L. Robertson.

M. D. Ross: L. A. Kilgore's discussion points out certain sources of error in the determination of specific heat constants for bodies which are subject to rapid heat interchange with adjacent bodies and his discussion is a valuable contribution to this phase of the problem. It is possible to make approximate calculations to determine the accuracy of the test results and from these calculations suitable corrections can be made.

T. A. Rogers has mentioned the use of this method of testing for losses in connection with the determination of the effective value of armature resistance and as an additional method to those described by B. L. Robertson's paper, "Tests of Armature Resistance of Synchronous Machines" (ELEC. ENGG., v. 53, July 1935, p. 705–9). Provided sufficient thermocouples are installed, the total stator losses can be determined with fair accuracy by this method. However, load losses in the rotor surface cannot be obtained with present test methods. The method involves building thermocouples into the machine at the factory and its present field is largely that of enlarging the machine designer's knowledge of the distribution of losses in the machine and the cause of these losses. The factory tests on turbine generators were not made with the idea in mind of determining the effective resistance of the machine as data available from the usual short-circuit loss test was considered satisfactory for this purpose.

Split Phase Starting of 3 Phase Motors

Discussion and authors' closure of a paper by G. F. Tracy and W. E. Wyss published in the October 1935 issue, pages 1068–72, and presented for oral discussion at the general applications session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

E. M. Sabbagh (Purdue University, West Lafayette, Ind.): The authors are to be complimented for the method of attack used in the analysis of this problem. The method of symmetrical components is a very powerful tool and its applications are numerous. However, the writer believes that less mathematical manipulations would be carried if the authors used the currents instead of the voltages in their solution. Thus from figure 1 of the paper it is seen that

$$I_a = \frac{V(jX + z)}{z\left(2R + 3z + \frac{jRX}{z} + 2jX\right)}$$

and

$$I_b = \frac{V(R + z)}{z\left(2R + 3z + \frac{jRX}{z} + 2jX\right)}$$

But

$$\check{I} = \frac{I_a\,\epsilon^{j30} + j\,I_b}{\sqrt{3}}$$

$$= \frac{V}{\sqrt{3}z}\left(\frac{\alpha X + jR - \sqrt{3}\,\alpha^2 z}{2R + 3z + \frac{jRX}{z} + 2jX}\right)$$

and

$$\hat{I} = \frac{I_a\,\epsilon^{-j30} - jI_b}{\sqrt{3}}$$

$$= \frac{V}{3z}\left(\frac{-\alpha^2 X - jR - \alpha\sqrt{3}z}{2R + 3z + \frac{jRX}{z} + 2jX}\right)$$

Hence

$$\check{I} + \hat{I} = \frac{V}{z}\left(\frac{jX + z}{2R + 3z + \frac{jRX}{z} + 2jX}\right)$$

$$\check{I} - \hat{I} = \frac{V}{\sqrt{3}z}\left(\frac{-X + 2jR + 3jz}{2R + 3z + \frac{jRX}{z} + 2jX}\right)$$

Torque $= 3r_2$ by the product of the in-phase components of $(\check{I} + \hat{I})$ and $(\check{I} - \hat{I})$

$$= \sqrt{3}\,r_2\frac{V^2}{z^2} \times$$

$$\left[\frac{r(-X - 3x) + (X + x)(2R + 3r)}{\left(2R + 3r + RX\frac{x}{z^2}\right)^2 + \left(3x + 2X + \frac{RXr}{z^2}\right)^2}\right]$$

$$= \frac{\sqrt{3}\,V^2 r_2}{z^2} \times \frac{2(RX + rX + Rx)}{\left(2R + 3r + RX\frac{x}{z^2}\right)^2 + \left(3x + 2X + \frac{RXr}{z^2}\right)}$$

which agrees with equation 17 of the paper. It should be noticed that this equation is only a special case of equation 1 of this discussion obtained from figure 1 of this discussion.

$$T = \frac{\sqrt{3}\,V^2\,r_2}{z^2} \times$$

$$\left[\frac{2(R_2(X_1 - x) + R_1(X_2 + x) + r(X_1 + X_2)}{D}\right] \tag{1}$$

Where

$$D = \left[\frac{(R_1R_2 + X_1X_2)r}{z^2} + \frac{(R_1X_2 + R_2X_1)x}{z^2} + 2R_1 + 2R_2 + 3r\right]^2 + \left[\frac{(R_1X_2 + R_2X_1)r}{z^2} - \frac{(R_1R_2 + X_1X_2)x}{z^2} - 2X_1 + 2X_2 + 3x\right]^2$$

If Z_1 and Z_2 be interchanged in the figure the direction of rotation of the machine reverses. In figure 1

$$\check{I} = \frac{V}{\sqrt{3}}\left[\frac{(Z_2 + z)\,\epsilon^{j30} + j(Z_1 + z)}{Z_1Z_2 + 2Z_1z + 2Z_2z + 3z^2}\right]$$

and

$$\hat{I} = \frac{V}{\sqrt{3}}\left[\frac{(Z_2 + z)\,\epsilon^{-j30} - j(Z_1 + z)}{Z_1Z_2 + 2Z_1z + 2Z_2z + 3z^2}\right]$$

$\hat{I}$ could be made zero and the currents in the motor balanced by making

$$Z_1 = \frac{\sqrt{3}\,X_2 - R_2 + R + \sqrt{3}\,x}{2} - j\,\frac{\sqrt{3}\,R_2 + X_2 + \sqrt{3}\,R - X}{2}$$

From figure 2 of the paper it may be seen that

$$\check{I} = \frac{V}{\sqrt{3}}\left[\frac{\sqrt{3}\,Rz + \alpha RX + (\alpha - 1)\,Xz}{3jXz^2 + 3Rz^2 + 2jRXz}\right]$$

and

$$\hat{I} = \frac{V}{\sqrt{3}}\left[\frac{\sqrt{3}\,Rz + Xz\,(1 - \alpha^2) - \alpha^2RX}{3\,jXz^2 + 3Rz^2 + 2jRXz}\right]$$

Hence

$$T = -\frac{V^2}{z^2}\,r_2\left[\frac{2\sqrt{3}RX(3z^2 + Rr + Xx)}{(3Rr - 3Xx)^2 + (3Rx + 2RX + 3Xr)^2}\right]$$

This agrees with equation 28 with the exception of having the rotation in the opposite direction and having $3z^2$ in the numerator instead of z^2.

This equation too is a special case of the equation obtained from figure 2 of this discussion.

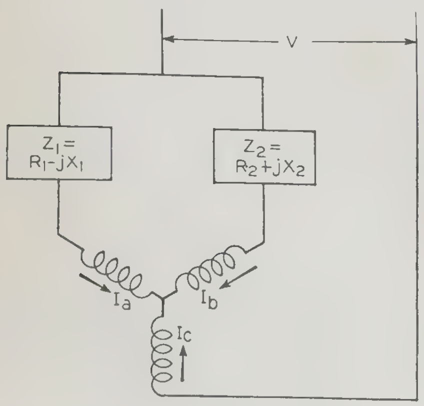

Fig. 1

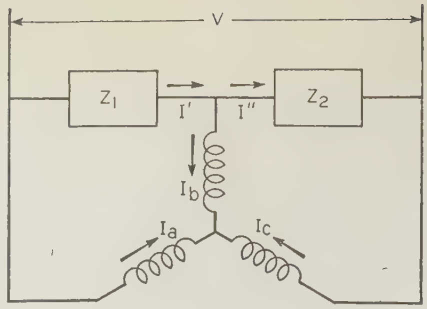

Fig. 2

$$\check{I} = \frac{V}{\sqrt{3}\,z} \times \left[\frac{(2zZ_1 + zZ_2 + Z_1Z_2)\,\epsilon^{j30} + j(zZ_2 - zZ_1)}{3zZ_2 + 3zZ_1 + 2Z_1Z_2}\right]$$

$$\hat{I} = \frac{V}{\sqrt{3}\,z} \times \left[\frac{(2zZ_1 + zZ_2 + Z_1Z_2)\,\epsilon^{-j30} - j(zZ_2 - zZ_1)}{3zZ_2 + 3zZ_1 + 2Z_1Z_2}\right]$$

$$\check{I} + \hat{I} = \frac{V}{z}\left[\frac{2zZ_1 + zZ_2 + Z_1Z_2}{3zZ_2 + 3zZ_1 + 2Z_1Z_2}\right] \qquad (2)$$

$$\check{I} - \hat{I} = \frac{V}{\sqrt{3}\,z}\left[\frac{j3zZ_2 + jZ_1Z_2}{3zZ_2 + 3zZ_1 + 2Z_1Z_2}\right] \qquad (3)$$

If resistance, inductance, capacitance, or combinations of resistance and inductance and resistance and capacitance are substituted in equations 2 and 3 of this discussion, the torque and its direction can be determined readily. It will be found also that the use of capacitance gives more torque than inductance and that an interchange of inductances, capacitances, and resistances in the 2 branches of the circuit changes the direction of torque.

L. T. Rosenberg (Allis-Chalmers Manufacturing Co., Milwaukee, Wis.): The authors present a clear treatment of the problem of determining the "best values" of external resistance and reactance for 2 types of split phase starting.

To apply the results of their work to a connection as in method 1 of the paper (figure 1) involves a series of successive substitutions of values first into equation 21 and then into equation 22 and so on. Fortunately the expressions lend themselves readily to a tabular arrangement of calculations and considerable effort may thus be avoided.

As an aid to further shortening the labor involved in method 1, it will be noted that for most cases the best values of X and R turn out to be such that $X+2x$ approximately equals $R+2r$. After the first calculation of R from equation 21 based on the assumed value of X, a second value of R can be computed at once by using a new X equal to $R - 2(x-r)$, thus eliminating one set of calculations. Moreover, a possible short cut approximate solution suggests itself by setting $R = X + 2(x-r)$ in equation 17 for torque, differentiating with respect to X, and equating to 0. The solution for X should be near the "best value," the corresponding R being, of course, $X + 2(x-r)$.

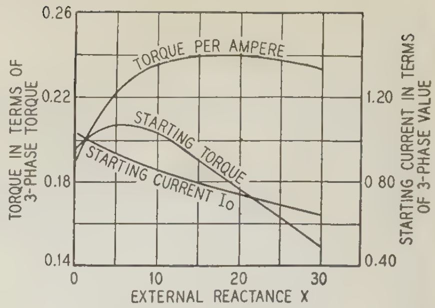

Fig. 3. Curves of starting current, torque, and torque per ampere for a 7.5-horsepower 440-volt motor

In treating the problem of method 1, the authors use those values of X and R which result in maximum starting torque without regard to the starting current. As a matter of further study those values of X and R resulting in a maximum value of torque per ampere may be of interest. If equation 17 be divided by equation 20 and the resulting expression differentiated with respect to each of the 2 variables in turn and equated to 0, we should have a pair of expressions corresponding to equations 21 and 22 which might be used together to obtain the values of X and R which yield the maximum torque per ampere of starting current.

In figure 3 of this discussion are shown curves of torque, torque per ampere, and starting current for a 7.5-horsepower 1,800-rpm 440-volt motor having the following constants: x = 16.8 ohms per leg; r = 6.3 ohms per leg; and z = 17.94 ohms per leg. The curves were computed from equations 17 and 20, but neither R nor X is held constant. Instead R is made equal to $X + 2(x-r)$ in anticipation of the result. The maximum torque is shown to occur at X= 5 for which R = 26. The complete solution after successive substitutions into equations 21 and 22 indicates the "best values" of X and R to be 6.5 and 26, respectively, and the maximum torque for the exact solution was within slide rule accuracy of that shown by the curve for this particular motor.

G. F. Tracy and **W. E. Wyss:** L. T. Rosenberg's observation that the best values of R and X are approximately equal to $(R+2r)$ and $(X+2x)$ respectively is a valuable contribution in that it cuts in half the number of computations involved in successive solutions of equations 21 and 22. Although such successive solutions present no particular difficulty, yet they are lengthy, and any scheme for reducing the time taken is very welcome.

E. M. Sabbagh's derivation of the torque equations by using the currents is perhaps somewhat shorter than that using the voltages. The authors, however, found little to choose between the methods except in the use of the expression for torque that involves the sum of the product of the real components and the product of the quadrature components of $(\check{I}+\hat{I})$ and $(\check{I}-\hat{I})$. His extension of the derivations to include the general cases where impedances of the form $R+jX$ are placed in both branches is interesting from a theoretical standpoint. The

conclusion that larger torques are obtained by substituting a capacitor for the inductive reactor is supported by experiment. From a practical point of view, each installation should be examined to determine whether the increased torque would warrant the increased cost of a capacitor. Sabbagh does not discuss the more practical aspect of the problem, namely, how to determine the *best* values of impedances to use in the various combinations. This aspect of the problem is the one with which the authors were chiefly concerned. The authors are grateful to him for pointing out the error in equation 28. This equation should contain $3z^2$ instead of z^2 in the numerator.

The A-C Electrolytic Capacitor

Discussion of a paper by C. F. Lomont and F. S. Dunleavey published in the October 1935 issue, pages 1058–63, and presented for oral discussion at the general applications session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

J. S. Malsbary (Wagner Electric Corp., St. Louis, Mo.): The authors state that for 110 volt capacitors the foils are formed at 165 volts (continuous), that is, 8 per cent above the actual peak voltage of 110 volts (effective). The design of capacitor motors sometimes necessitates relations which result during the starting period in a voltage across the capacitor which is greater than the line voltage (110 volts). The question arises as to how much, if any, overvoltage can be placed during the starting period across standard 110 volt electrolytic capacitors? The authors' opinion on this point would be valuable.

This would seem to raise the point of what happens in an electrolytic capacitor when the actual peak of the operating voltage exceeds the formation voltage. This point has been partially taken care of by the authors' curves of watts against volts which when plotted on logarithmic paper show a definite break in the line at the formation voltage. However, nothing is said with regard to the change in effective life of the capacitor as a result of this increase in voltage.

The authors' method of determining the voltage at which an electrolytic capacitor has been "formed" by plotting the watt-volt curve on logarithmic paper may prove to be a very practical method for comparing capacitors of different makes. It appears also to be promising for checking the constancy of the manufacturer.

A number of capacitors have been tested in the manner described in the paper, and the character of the plots obtained by us is identical to that of the curves in figure 3 of the paper. The life tests made by the authors at different temperatures are very instructive. They forcibly show the importance of holding the ambient tempertures as low as possible. It is hoped that the authors' suggestion to develop a satisfactory standard method of test will soon be a reality, as it certainly would be of great value to the manufacturer as well as to the user.

F. W. Godsey, Jr. (Sprague Specialties Co., North Adams, Mass.): I wish to point out an inconsistency in this paper which, while it does not influence the main body of the paper, leads to erroneous conclusions as to the mode of operation of a-c electrolytic capacitors.

The authors state that at any given instant the charging current of the capacitor consists of the capacitance current of one filmed electrode only, and that the other filmed electrode could be replaced by an unfilmed electrode without in any way affecting the instantaneous performance of the capacitor as a whole. This statement is much in error.

According to the authors' own statement and reference 1 of the paper, under steady state conditions the electrolyte carries a constant and unvarying negative charge Q. Since the electrolyte is in series with the 2 filmed electrodes, if a displacement current takes place between the electrolyte and one filmed electrode with no conduction current, then the current flow in the series circuit between the electrolyte and the other filmed electrode must also be a displacement current. If conduction current took place, such as would be the case if an unfilmed electrode were substituted for the filmed electrode, then there would be an electron flow to the electrolyte, increasing the charge Q which previously has been stated to be constant.

Conduction current does flow when voltage is first applied to the capacitor, but it flows only long enough to establish the charge Q, a matter of a few cycles until equilibrium conditions are reached, after that only displacement current flows with a negligible amount of true leakage conduction current present.

The voltage relations as shown in figure 1 of the paper do not agree with experimental results or advanced theory. In practice, the electrolyte charge Q is found to be approximately 75 per cent of the maximum theoretical figure in the case of aluminum electrodes ("A-C Capacities of Electrolytic Capacitors," F. W. Godsey, Jr., Electrochem. Soc. *Trans.*, v. 61, 1932, p. 523). This means that across the nonconducting or rectifying region of each film, there appears only 75 per cent of the maximum theoretical alternating component of voltage; in the case of a 110 volt capacitor, the actual electrolyte charge is about 58 volts (continuous) as compared with the maximum theoretical of 77.5 volts; and the effective alternating voltage across the nonconducting or rectifying region of each filmed electrode is 41.2 volts instead of the maximum theoretical value of 55 volts.

The difference between 55 and 41.2 volts appears in the outer semiconducting film layers and in the electrolyte as displacement charges, electrolytic polarization, and resistance drop. This difference does not add to the 41.2 volts exactly in phase, the out of phase angle depending upon the power factor of the capacitor. Thus, the alternating voltage drop in the outer film layers and electrolyte associated with one electrode may amount to from approximately 14 to 20 volts, depending upon conditions. This is illustrated in figure 1 of this discussion which shows the real continuous electrolyte potential, the alternating voltage across the nonconducting region of the film, and the total alternating voltage applied to one electrode and its associated electrolyte; 55 volts in the case of 110 volt capacitors.

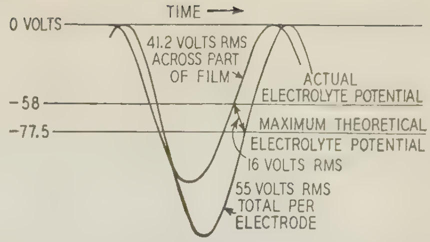

Fig. 1. Potential relations in a-c electrolytic capacitor

Typical capacitor of type used for motor starting; individual capacitors will vary somewhat from these figures

The alternating voltage drop in the outer film layers and in the electrolyte is the difference between the total electrode voltage and the nonconducting film voltage, taken as 16 volts root mean square in the illustration. The action that is simultaneously taking place at the other electrode is similar except that it is shifted on the time axis 180 electrical degrees.

The authors' statement of a need for standard life test method for a-c electrolytic capacitors is timely. A paper is now in preparation discussing various test methods for a-c electrolytic capacitors.

Magnetic Fields in Machinery Windings

Discussion and author's closure of a paper by J. F. H. Douglas published in the September 1935 issue, pages 959–66, and presented for oral discussion at the general applications session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

Sterling Beckwith (Allis-Chalmers Manufacturing Co., Milwaukee, Wis.): The author has chosen an intricate subject and succeeded in adding to it a useful concept of the process necessary in superposing certain magnetic fields. His methods, while somewhat limited in application, are more simple than may be apparent on the surface. As an illustration of this simplicity, figure 3 of the paper may be considered. Here it will be noted that to obtain the resultant flux lines, it is necessary merely to draw them through consecutive intersections of the horizontal and vertical lines representing component fields, so that as soon as one resultant flux is drawn, the others follow automatically.

Mention is made of the fact that most textbook formulas for field leakage flux do not give answers of sufficiently large magnitude. In the first place they do not allow adequately for the fringing flux between pole tips (that represented by ΔH in figure 3) and in the second place they do not take account of the flux from the side of the pole to the yoke (that flux which does not cross from one pole to the other in figure 3). I can substantiate both of these observations from practical experience. The extra fringing flux between poles tips is the

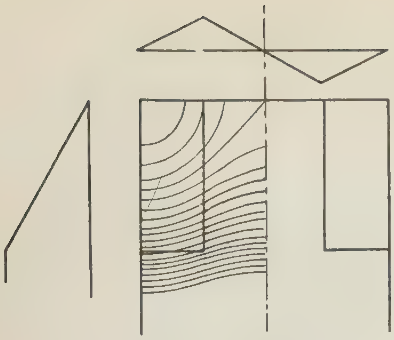

Fig. 1

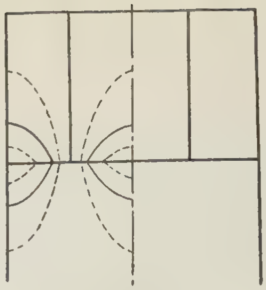

Fig. 2

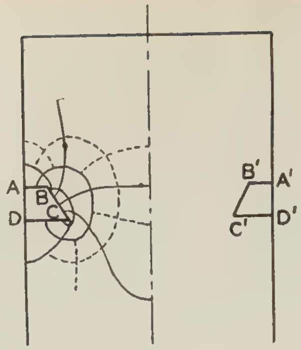

Fig. 3

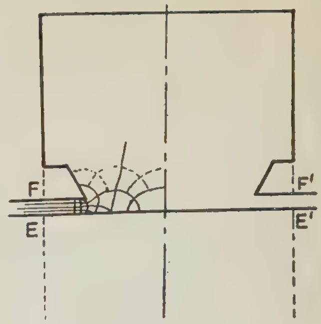

Fig. 4

more important of the 2, and I have found it necessary to allow for it in order to obtain satisfactory saturation curves from calculations. The yoke flux becomes important in calculating Potier and equivalent reactance, especially where there is appreciable pole saturation and where the number of poles in the machine is small.

This paper and the method it presents should make possible the derivation of more theoretical and more general formulas for field leakage than those now used.

As the author suggests, the rectangular boundary lines which can be treated by his method of superposition can be altered by other graphical methods to give fields for the actual boundary conditions. I should like to suggest a means for doing this in one particular case, in order to indicate a somewhat general method which is largely an extension of his method of superposition. In figure 1 of this discussion is shown the main field of figure 3 of the paper. In figure 2 of this discussion is shown a compensating component which was not allowed for by the author in obtaining his figure 3, but which will probably add to the exactness for the purposes of this example in view of the steps to follow. Now consider the area $ABCD$ of figure 3 of this discussion and suppose that the boundary of this area is made a magnetic shell, and so magnetized that it exactly neutralizes the flux it cuts when superposed on figure 1 plus that which it cuts when superposed on figure 2. If area $A'B'C'D'$ is similarly treated, it should then be possible by graphical methods to approximate the field produced by this shell as has been done in figure 3. When fields 1, 2, and 3 are then superposed, the surface $ABCD$ becomes a surface of zero potential, and can be considered as an iron surface such as the pole tips.

The next step is to treat the surfaces EF, $E'F'$, and EE' in figure 4 of this discussion as magnetic shells of such magnetization that in the case of EE' the flux across it is exactly neutralized, and in the case of EF and $E'F'$, the intensity is sufficient to raise the points E and E' to the desired potential (i. e., half the total ampere turn lines must cross the line EF and half cross the line $E'F'$). The flux field set up by these shells can then be plotted, after which the superposition of figures 1, 2, 3, and 4 gives the desired field. Note that the magnetic shells discussed are not necessarily magnetized at right angles to the surface, and consequently differ from the usual magnetic shells. (See J. H. Jeans, "Electricity and Magnetism," fifth ed., Cambridge Univ. Press, p. 376, and reference 4 of Douglas' paper.) Also note that component 3 of the paper is not perpendicularly magnetized.

The chief claim for the method outlined in this discussion is that the component fields 1 and 4 are relatively weak in the region of the main field conductor of figure 1 so that even though the field is not Laplacian in the conductor, the error in assuming it to be so for the component field is small. Furthermore, the component fields are of such choice that they are relatively easy to plot graphically. If desired, the magnetic shell EE' can be made of such magnitude that it allows for the termination of some ampere-turn lines on the armature conductors between E and E'.

J. F. H. Douglas: Sterling Beckwith's suggestion as to the use of magnetic shells to allow for the effect of pole tips is interesting. One might infer that the simpler treatment in the article was inaccurate, although he does not give a numerical comparison, and the method he proposes proved too arduous for the writer to undertake.

The solution of pole tip leakage was therefore checked by 2 methods: (1) the Rayleigh partition method, and (2) a new resolution into main and compensating fields allowing for pole tips. The former yields a leakage factor 0.5 per cent lower than the latter method.

In figure 3 of the paper a line was drawn as the boundary between pole side and pole tip leakage. (Line AA' in figure 5 of this discussion.) If this be regarded as a Rayleigh partition, it is to be noted that on one side we have a vortical field, and on the other side a substantially lamellar field, which can be determined by graphical methods or by a use of the Schwartz-Christoffel transformation. The error involved in placing a Rayleigh partition is always small if the partition is near its correct position, and the permeance is always a trifle too low.

Instead of computing the shells proposed by Beckwith, I have computed in figure 5 a new main component field using the Schwartz-Christoffel transformation for locating the ends of the lines of force. I used the sectorial area rule for adjusting the spacing in the vortical region, and used the graphical method for adjusting their shape and the lines of no work. The numbers indicate ampere-turn values and flux function values.

In figure 6 of this discussion I have computed a revised compensating component of the field. This was constructed by the use of a special magnetic shell along the line BB'. I have not superposed these 2 fields, except to sum up the pole leakage which

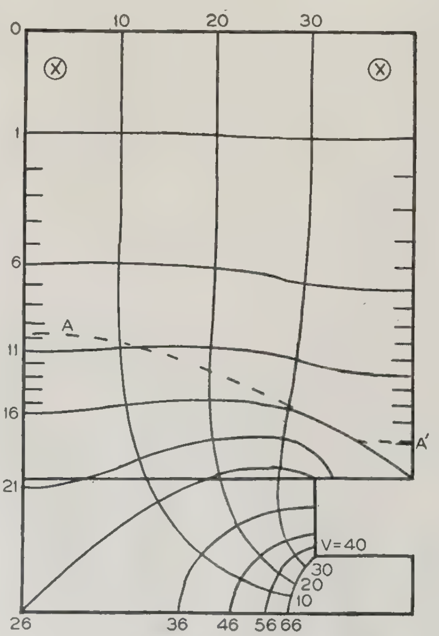

Fig. 5. Main component of field

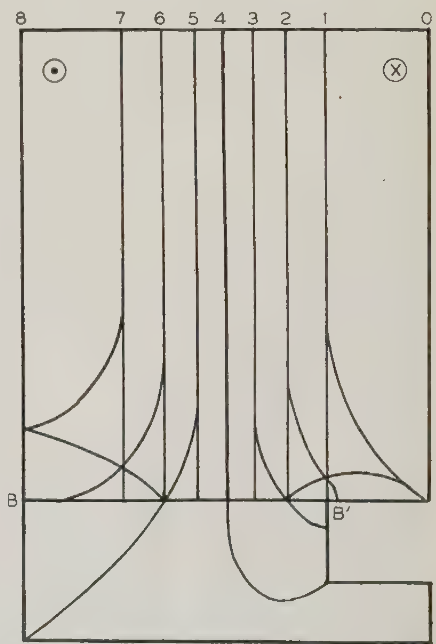

Fig. 6. Compensating component of field

checks with the 0.5 per cent value cited.

Beckwith's component 2 was shown in figure 6 of the paper. In discussing his figure 3 he speaks of a shell magnetized so as to exactly neutralize flux; he means of course potential as is shown by this figure.

I would like to mention at this point that the Schwartz-Chistoffel theorem in the functions of a complex variable is not enough appreciated. Contrary to the usual opinion it is capable of handling quite complicated boundaries. The full power of the method is not realized, however, unless combined with other principles. For vortical fields it must be united with the sectorial area rule. For complicated boundaries it must be used with Rayleigh partitions. For root determination numerous artifices must be resorted to, many of which are not published. For integration, graphical integration, and integration in series elleptic functions are of considerable aid.

What is really needed to complete this subject, it seems to me, is a series of experiments using Mullner's method for mapping vortical fields.

A New Watt-Hour Meter

Discussion and author's closure of a paper by Stanley Green published in the October 1935 issue, pages 1073–84, and presented for oral discussion at the general applications session of the Great Lakes District meeting, West Lafayette, Ind., October 24, 1935.

H. B. Brooks (National Bureau of Standards, Washington, D. C.): This unusually frank and very informative paper makes a complete break with the time honored policy of secrecy concerning the design of electrical measuring devices. Not the least interesting feature is the revelation of the very close touch which exists between the engineers who use watt-hour meters and the meter designer. This close co-operation is largely responsible for the superiority of meters of American manufacture over those made in countries where the user and the designer do not work together as they do here.

The author's comments on the fact that present American watt-hour meters can carry continuously 300 per cent of rated current bring up the question as to whether the time is not drawing near for adopting a more logical system of rating. This would involve some readjustment of our thinking. For example, where we now think of 10 per cent of rated current as the conventional light load, we would have to consider 3 per cent as light load. Values of torque-weight ratio would become more impressive by a factor of 3; the full-load speed of the disk, and the watts loss in the current coil, would appear relatively large, until meter users became accustomed to the new basis. Aside from the illogical aspect of rating a device at only a third of the load which it will carry continuously and measure accurately, 2 other defects of the present method of rating occur to me. The first is that the provision of meters of 5, 15, and 50 amperes rating appears to leave gaps and not to go high enough; for example, one would naturally expect 10, 25, and 100 ampere ratings also. There is no hint, in the rating "50 amperes," that loads up to 150 amperes can be carried safely and measured accurately. The other reason is that the illogical rating fails to suggest the proper meter for special applications, for example, metering with current transformers. Here a nominal 5 ampere meter is not the right thing, but a nominal 2.5 ampere meter, which is actually capable of handling safely and accurately the upper limit (say 7.5 amperes) of the secondary of the transformer.

The fact that all designing involves compromises comes out very clearly in figure 6, which shows, for example, that a meter can be designed to have a high torque with a small stack thickness, but at the expense of greatly increased loss in the potential element; or it can have high torque with a low loss if the user will accept the extra weight and cost of greater stack thickness.

The author has covered the technical aspects of his subject so completely as to leave little room for discussion from that aspect. The practical consequences of his thorough study of the electromagnet are shown in the attainment of 10 per cent greater torque with 25 per cent less material and 10 per cent smaller loss in the potential winding.

It is to be hoped that we shall have more papers like the present one. Commercial success depends on many things besides "trade secrets." Every engineer begins his work with the accumulated experience of the race at his disposal, and he should feel ashamed to finish his work without having made a substantial contribution to recorded knowledge.

D. T. Canfield (Purdue University, West Lafayette, Ind.): The watt-hour meter art, until very recently, has been characterized by a serious lack of technical publications either in the form of papers or textbooks. To those of us who are interested in teaching the fundamentals of the art to engineering students this lack of suitable printed material for a reference has been a great handicap to effective instruction.

Manufactures of watt-hour meters in the past have been exceedingly reticent in divulging any information as to the whys and wherefores of their designs. The writer's bookcase is half full of manufacturers' literature on meters apparently written, edited, and published by the sales department for the obvious purpose of selling the product described therein. Beautifully engraved performance curves showing astonishing accuracy under all manner of conditions fill these pages, but rarely if ever is there one word as to how this has been accomplished and what are the merits of their particular way of doing it. In teaching applied design we are interested in the result only in so far as we are able to explain the method of obtaining that result.

Having been associated with the author and his company for some years it is not the writer's intention to comment on the merits of his design, but rather to compliment him for what, to pedagogues at least, is a more important and per chance a more lasting accomplishment: namely, having designed a new meter whether good or bad, he has had the courage to lay his cards on the table and tell us why he did what he did. This paper may be the first fruit of a new area, wherein will exist a more open door policy between manufacturers and between manufacturer and the public. It is no longer as difficult as it was to obtain co-operation between these elements.

O. A. Knopp (Pacific Gas and Electric Co., Emeryville, Calif.): The paper is indeed a fine exposition of the art of meter design. The author has shown all the phases of the design of a modern meter and has demonstrated how a very good design can be obtained by carefully compromising between all the essential elements entering into the design, such as ease of manufacture, ease of repair, ease of adjustment in the shop and in the field, light weight, small losses, and good torque, together with high accuracy over a wide range under varying conditions of temperature, voltage, and frequency. It is evident that a very happy compromise has been attained, resulting in a meter which can be classed among the best modern watt-hour meters, possessing particularly strong features appealing to the meter men, that is, accessibility and convenience of adjustment and repair.

Many of the features of the design are of interest, but particularly the straight line registration curve. As early as 1917, the writer was hammering at all the meter manufacturers and was urging the meter committee to put pressure to bear with these manufacturers for the elimination of the overload droop of the current characteristic of the meter, for the power companies were losing large revenues because the 5 ampere meters frequently were being operated on currents of 10 and 15 amperes. This was especially apparent on the West Coast, where domestic consumers were using electricity more freely than elsewhere.

In the April 15, 1919, issue of the *Journal of Electricity* in an article entitled "Increasing Revenue by the Watt-Hour Meter," the writer described a device for straightening the curve of the standard watt-hour meter. This device consisted of a tiny electromagnetic shunt which could be attached, either externally or internally, to the watt-hour meter, shunting off a small amount of current from the current coil of the meter. As the overload on the meter increases, this device shunts less and less current, due to its becoming more and more magnetically saturated, and thus straightens out the

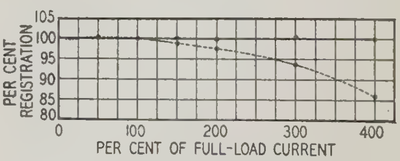

Fig. 1. Registration curves of watt-hour meter

Dotted curve without curve straightening device; torque 35 millimeter grams

Solid curve with curve straightening device; torque 26 millimeter grams

Meter must be calibrated for both inductive and noninductive loads when curve straightening device is used

curve of the meter in a remarkable fashion.

It may be appropriate at this time to refer (figure 1 of this discussion) to a curve which was made by the Duncan Electric Manufacturing Company in 1922 on a Duncan meter which had been equipped by the writer with the curve straightening device. At the same time meters of other makes were similarly equipped and sent to each of the manufacturers, in order to induce them to straighten out the curves of their meters so that operating revenue might be increased with meters purchased from them.

It was even contemplated to go so far as to attach such a device in or to meters in service, if the manufacturers would not straighten the curves. A few years later, one of the meter manufacturers who had become convinced that such improvement should be made introduced a straight line meter, using a magnetic shunt instead of an electromagnetic shunt, accomplishing essentially the same results; and later on the Duncan Company followed suit with the device described in the paper, which fundamentally is also a magnetic shunt which, in saturating, shunts less and less on overloads, thus straightening the accuracy curve of the meter.

Curves in figure 7 of the paper show that the same amount of shunting was used in his device as was required with the writer's device, namely, some 20 to 25 per cent to obtain a straightening of the curve up to 300 and 400 per cent load. With either method, there is a decrease in torque which has to be made up by increasing the total flux threading through the disk.

The remarks made by the author regarding the subject of watt-hour meter bearings are very pertinent. The writer agrees that further improvements are desirable and possible, particularly along the line of the inverted bearing, having the cupped jewel at the end of the shaft and the pivot below, to prevent the accumulation of dust and debris from gumming up the oil and causing continuous friction and bearing wear.

Stanley Green: Commenting on D. T. Canfield's remarks, it would seem that every time a complete change in design of a line of watt-hour meters is made, there must be considerable improvement embodied in the new design or it would not be produced. An explanation of the reasoning underlying the new design and the interrelation of the various problems should have some pedagogical value. It would indeed be discouraging to believe that future meter design is not going to be interesting enough to have new features of an educational value.

There would seem to be many arguments in favor of H. B. Brooks's suggestion that modern meters be rerated in conformity with their true current carrying capacity. Possibly the most plausible explanation of why this has not yet been done is that there are many millions of meters still in service without the overload capacity of the newer types. Furthermore, test procedure and the rulings of many state regulatory bodies are built up on the basis of the old nominal current rating. This makes a changeover difficult. In addition to this, it is probable that meters will always be tested in the field with current values close to the present scale of nominal current ratings because of the extra cost and weight of loading equipment necessary to supply the higher current values.

I am glad that O. A. Knopp brought out the fact that overload compensation is not broadly new. As he states, it has been understood as far back as 1919, or even before, that some sort of a saturable member could be used to straighten out the registration curve of a meter. The only thing novel in the present instance regarding the overload compensation used is the particular method of its application, and the structure and slotting of the plate employed, so that the same overload compensator can be applied to an entire line of meters with precision results, not only on unity power factor, but on fractional power factors. Many schemes of employing the saturable member have been proposed in the past, and the choice of any one scheme has always been a problem for the manufacturer with respect to any particular design. It is believed that the structure of the present overload compensator is a particularly fortunate one for the new line of watt-hour meters described.

The Hawaiian Radiotelephone System

Discussion and authors' closure of a paper by W. I. Harrington and C. W. Hansell published in the August 1935 issue, pages 822–8, and presented for oral discussion at the communication session of the Pacific Coast convention, Seattle, Wash., August 28, 1935.

Abe Tilles (University of California, Berkeley): It is implied in the paper that the directional nature of the beams is the chief source of privacy. A glance at the polar diagram of figure 5 of the paper, however, would indicate the contrary. This diagram shows that the signal is above half maximum for about 20 degrees either side of the direction of maximum signal. Now such a beam, reasonably strong over a total width of 40 degrees, would cover completely a fair sized island one or 2 hundred miles distant. The directivity achieved is, of course, excellent, but it hardly seems possible that it can restrict reception specifically to a small area when the distance is as great as 200 miles. Is it not likely that the satisfactory privacy actually attained is primarily to be attributed to the necessity for really expert adjustment of the receiving antenna, rather than to the directivity of the beam?

In regard to the experimental channel in the $1^1/_2$ meter range, it is stated that an unobstructed optical path exists. To what extent do tests show this to be imperative? In the short wave communication system used during construction of the San Francisco-Oakland Bay Bridge it turned out contrary to initial fears, that the shadow of Yerba Buena Island was not sufficiently strong to cause practical difficulties. Of course, that communication was at somewhat greater wave lengths than the system described in this paper. With these ultra-short waves does test indicate a complete shadow beyond an obstruction or do these waves, too, refract about a mountain or island to a considerable extent?

W. I. Harrington and **C. W. Hansell:** Replying to the questions of Abe Tilles, we agree that directivity of the transmitting antennas does not contribute much to privacy in so far as reception on distant islands in the general direction of the beam is concerned. Privacy at great distances is primarily due to the necessity for first class receiving antennas and equipment not usually possessed by casual or amateur listeners. However, as indicated in the paper, the directivity is an important factor in reducing the probability of unauthorized reception on the island on which the transmitter is located. Ground reflection, which was not taken into account in the directive patterns of figure 5, tends to increase the vertical directivity and reduce the signal strength at ground level. This effect of ground reflection makes necessary the great heights of transmitter and receiver for working great distances.

A direct optical path is not essential to ultra-high frequency communication but is very desirable. When the optical path distance is exceeded on relatively long circuits the rate of falling off of signal strength is increased above that observed within the optical distance and fading becomes a more serious hazard to continuous communication. The shadowing effect of obstacles increases with increasing frequency but, as in the case of light, is not complete. We presume the short distances worked in connection with the San Francisco-Oakland Bay Bridge made communication relatively easy so that small obstacles such as Yerba Buena Island were not a serious handicap.

Spark Lag of the Sphere Gap

Discussion and author's closure of a paper by Abe Tilles published in the August 1935 issue, pages 868–76, and presented for oral discussion at the electrophysics and measurements session of the Pacific Coast convention, Seattle, Wash., August 29, 1935.

R. C. Mason (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): It appears that the author has been too hasty in drawing his conclusions; though the division of spark lags into 3 domains may seem reasonable, the experimental evidence presented in this paper is not sufficient to prove that such an allocation actually occurs.

1. The first domain is described as containing the relatively long time lags spent awaiting the arrival of a suitable arrangement of initiatory electrons. Now, in his experiments, the initiatory electrons are provided by ultraviolet radiation on the spark gap. The number of electrons freed from the cathode will be proportional to the first power of the intensity of radiation. It is unlikely that any electrons are produced in the gas by the radiation, but if such ionization does occur, the rate of production of electrons will be proportional to the first power (or higher power, if ionization is by a cumulative process) of its intensity. Any increase in the number of electrons present by multiplication of initial electrons by the action of the electric field in the prebreakdown stage will be propor-

tional to the number produced by the ultraviolet radiation. Hence, the reciprocal of the mean time lag, or probability of spark-over p, should be proportional to the first, or higher, power of the intensity. Instead, it was actually found that $p \alpha I^{0.76}$. Some factor other than the rate of production of electrons must affect the time lags.

2. The author states that all spark lags consist of initiatory lags followed by formative lags. The shape of the spark lag distribution curves in the "transition" region does not agree, however, with the idea of 2 independent time lags. If the formative lags were all of the same value, the plot of n_t versus t on semilog paper should give a straight line with n_t = 100 per cent at t = formative lag. If instead of a unique value the formative lags have a peaked distribution about a mean value, n_t versus t should be a straight line for t much greater than the mean value of the formative lag, and then n_t should rise *above* this straight line for values of t in the neighborhood of the mean formative lag. Actually, exactly the opposite behavior is exhibited, as in figure 4*c*. Thirty per cent of the spark lags are about 10^{-4} seconds, which Tilles ascribes to formative lags. In the interval from 10^{-4} to 6×10^{-4} seconds, where according to a random distribution of initiatory lags 30 per cent of the time lags should be found, only 5 per cent actually occur. The presence of the short formative lags has influenced the distribution of initiatory lags which are supposed to have preceded them!

All spark lags observed in the first domain should be longer than the formative time lag, which Tilles puts at 10^{-4} second, but if a sufficient number of tests are made, then some of the lags should be very close to the formative lag. The curves for weak radiation, however, such as *a* and *b* in figures 4, 5, and 6, seem to show very long minimum lags—almost 0.1 second in one case.

3. The second domain of formative time lags represents the time required for space charges to begin to distort the field. It is true that space charge distortion will be appreciable after a time of the magnitude of that required for a positive ion to travel from anode to cathode. That time, however, is not 10^{-4} second, but far shorter, as may be seen as follows:

The mobilities of positive ions are usually measured under experimental conditions far different from those encountered here—measurements are made with weak fields and with ions aged at least 10^{-4} seconds and often a few tenths of a second; in this case, the field is strong (5.6×10^4 volts per centimeter) and the ions are freshly generated, probably reaching the cathode in their molecular form. Experimental values of mobilities of positive ions in weak fields are: in air, 2.2; in pure nitrogen, 2.09 to 2.7; in impure nitrogen, 1.6. If the lowest value is taken, the velocity in the author's spark gap would be about 9×10^4 centimeters per second. The mobility of molecular ions in nitrogen for E/p up to 36 has been measured by Mitchell and Ridler (Royal Soc. *Proc.*, v. A 146, 1934, p. 918); if their results are extrapolated to the value of E/p occurring in the spark gap, a value of mobility of 4.2 is found, giving a velocity about 2.4×10^5 centimeters per second. If the mobility to be expected is calculated from the Langevin formula (*Rev. Mod. Phys.*, v. 2, 1930, p. 221) 6.9 is obtained, giving a velocity of 3.9×10^5 centimeters per second. Since the gap length is 0.0683 centimeter, the time of transit of a positive ion from anode to cathode, using the extremes of the above mobilities, would be 0.75×10^{-6} or 0.17×10^{-6} seconds. Uncertainty in the correct mobility can hardly increase the transit time above 10^{-6} seconds, instead of the almost 100 times longer interval used by Tilles. His observation of change in the distribution of spark lags at about 10^{-4} seconds cannot be said to establish experimentally the existence of the second domain as defined by him.

In view of the discrepancy between the experiments and the theory as presented in the paper, it would seem important to make sure no spurious experimental results were obtained, by checking the time lags by means of a cathode ray oscillograph.

Morris Newman (nonmember; University of Minnesota, Minneapolis): From the paper it appears (figure 3*b*) that the time lag may be 0.05 second or 50,000 microseconds for an overvoltage as high as 5 per cent. In impulse potential measurements with sphere gaps as carried out in practice, such high time lags would appear somewhat surprising as they would certainly lead to differing results greatly dependent on the duration of the impulse wave. Perhaps under the more usual laboratory test conditions of higher impulse voltage and consequently larger spheres, the time lag may be considerably shorter. I should like to have the author discuss this and briefly compare his results with contemporary work reported in the literature on the subject.

Also, I should like to ask what was the lowest time lag recorded on the special instrument developed, and whether, at the lower time lags, any comparative work has been done with the cathode ray oscillograph? Generally in lightning protection work we are concerned with impulse potentials of appreciable overvoltages and consequently very short time lags; therefore, the question of minimum time lags measurable is of interest, since the application of the instrument developed by Tilles might be of considerable value in obtaining volt-time characteristics in connection with insulation co-ordination test work.

Abe Tilles: In regard to Morris Newman's question as to why the large initiatory lags do not influence various measurements of sparking voltage of impulse spark-over, the answer is twofold. In the first place, they do. This is evidenced by the confusion prevalent in the earlier impulse measurements before wave shape and time factors were standardized, as mentioned in reference 1 of the paper. It is also evidenced in the recent excellent article by G. L. Nord[18]. In the second place it should be appreciated that the initiatory ionization available at impulse spark-over may well be very much greater than at steady state spark-over. The reason for this is that the slowly rising sine wave voltage sweeps all electrons out of the gap, so that when the voltage has finally become adequate the spark must await the formation of a *new* electron by the ionizing sources. The impulse wave may rise so rapidly as to reach sparking potentials before the electrons initially in the gap have been removed. Accordingly, the impulse spark-over can utilize any of the electrons present in the gap as residue from all previous ionization. For this reason the initiatory lag of impulse spark-over can well be entirely negligible. Use of high overvoltages, common in impulse testing, gives a greater gap volume within which initiatory ionization can be effective, and thus also acts to reduce the initiatory time lags.

Finally, in answer to the question concerning the use of this instrument for measurement of the very short time intervals, the instrument on hand is usable for intervals down to 10^{-5} seconds. This instrument is however, entirely suitable in principle, I believe, to measure intervals as short as 10^{-7} or 10^{-8} seconds. For such use the instrument would need to be rebuilt with a better quality of construction, shorter leads between tubes, etc. In general the same standards of construction would need to be observed as apply to ultra-short wave, i. e., 3 meter, radio equipment. For the most brief intervals the electro-optical shutter as used by R. R. Wilson[19] and references 4 and 6 of the paper appears most useful.

Anong R. C. Mason's objections some points of interest are raised. These, and many others it must be recognized, could not be discussed in full detail in the original paper because of limitations of space.

1. Under the first numeral he observes that, the liberation of electrons being proportional to the intensity of ultraviolet radiation, and the probability of spark-over within unit time being proportional to the 0.76 power of intensity, "some factor other than the rate of production of electrons must affect the time lags." This conclusion, based on the experimental results, is correct. It does not contain, as Mason appears to imply, any contradiction to the quotation at the beginning of his paragraph that the relatively long lags are spent "awaiting the arrival of a *suitable* arrangement of initiatory electrons." (Italics mine)

It might be of interest to point out some factors other than the gross rate of production of photoelectrons that affect the time lags. Obviously one such factor is the location of the liberated electrons. Since the radiation is at right angles to axis of the sphere gap, the photoelectric threshold intensity (neglecting, for a first approximation, the reflection of radiation from the other sphere) can never be obtained at the gap axis, where the sphere surface is parallel to the radiation. For low levels at radiation, accordingly, only the sphere sides are effective in photoelectric emission. As the intensity is increased the area so effective creeps in toward the sphere axis at an ever diminishing rate. Accordingly, a power of the radiation intensity less than unity is introduced into the spark probability.

Another factor entering the total sparking probability is the probability that the production of a photoelectron anywhere in the gap will produce a spark. Any assumption that this probability is constant at unity is obviously erroneous. On the contrary an entrance here of the law of diminishing returns is not unexpected. Thus, Schumann[20] and his student Sämmer[21], in a mathematical investigation of this particular question, found that photoelectric emission of an isolated electron, or at an isolated

element of electrode area, is definitely *more* effective in producing sparking conditions than emission of a sheet of photoelectrons over the whole electrode surface. Since, as the radiation is increased from a very low value, the emission changes from emission of individual electrons isolated in time to emission of a more continuous sheet over the entire emitting area, it is not surprising, accordingly, that the sparking probability will increase with radiation intensity but that this increase will be less than linear.

It would be quite difficult to interpret properly all factors entering the phenomenon and thus be enabled to predict the exponent in a particular case as being 0.76 or, as Mason insists, 1. In this case, at any rate, his implication that the observed dependence of spark lag on radiation must be erroneous, *ipso facto*, because it is nonlinear, is quite unwarranted.

2. Mason raises a group of objections implying that the data must be in gross error because they do not fit perfectly certain mathematical lines. I am quite willing to meet him halfway, so to speak, and admit freely that the experimental curves may not coincide perfectly with the typical facts of the case. This is to be expected because a series of tests which are quite multitudinous from an experimental standpoint may yet be insufficient in number from the standpoint of statistical perfection. Moreover, if in a transitional distribution of 50 spark lags, such as curve *c* in figure 4, the number of lags in the actual "transitional" portion of the distribution is some 20 per cent of these 50, deviations are to be expected. That in one case 8 lags and in another 12 should fall apparently "betwix and between" is, it would seem to me, no cause for alarm. I would venture to predict, in contradiction to Mason's expectations, that more perfect measurements of the transition region would disclose, not more simple, sharply breaking curves, but more elaborate fine detail in what is, after all, a statistical survey of a most complex transition. It is of interest that curve *d* of figure 4, involving more points in a single distribution, gives very nicely the distribution expected for the formative lags, as do also curve *a*, etc., for the initiatory lags.

Specifically, Mason states that a distribution of formative lags must result in a curve "above the straight line" of the curve with all formative lags unique. On the contrary, if some of the formative lags are somewhat less than a unique central value, some of the time lags being smaller, the curve must be drawn to the left of, i. e., under, the straight line mentioned.

He states also, in connection with the small flat portion of curve *c*, figure 4, that between 10^{-4} and 6×10^{-4} seconds "only 5 per cent" of the lags of that distribution occur. It may be easily measured on the curve that 78 per cent of the lags are greater than 10^{-4} seconds and 60 per cent are greater than 6×10^{-4}, the percentage intervening, therefore, being not 5 but 78 minus 60, or 18.

In response to his further remarks on this point, it may be stated that the shortening of the initiatory lags as a whole to the point where some of the formative lags become evident in the distribution curve may not decrease the magnitude of some individual longer initiatory lags of the series, but it does alter most substantially the position on the distribution curve of these lags of longer duration.

In test series involving longer lags throughout, a few of the smallest lags were measured with relatively low accuracy, thus producing the small zero deviations which Mason mentions. Thus, curve 1, figure 5*a*, whose average lag is 0.4 second, was taken entirely with the synchronous timer, the sensitive galvanometers being short-circuited throughout the series. It has, accordingly, the largest zero deviation of any of the curves, this deviation being, as is easily seen from the figure, 0.05 second. Mason takes this deviation, arbitrarily doubles it, and compares it, not to the series in which it occurs, but to the absolute value observed as the minimum time in series having the shortest lags, an unfair comparison. In no case were the conclusions of this work based on slight marginal deviations, nor can they be invalidated by pointing to such.

After detailed consideration of these various objections, it still seems that the data presented do establish the primary fact which has been challenged here; namely, that the time lags fall into one or the other of 2 distinct distributions, one of initiatory lags, the other of formative lags, and that the distribution changes from the first to the second through an observed transitional distribution as the radiation intensity is sufficiently increased.

3. The point that the formative time observed at the low overvoltages used is longer than the available estimates of the time of transit of a positive ion across an un-ionized gap is of interest. Mason appears to misunderstand my paper, however. Detailed agreement between these 2 intervals would be unexplicable if observed and is nowhere in this paper stated or implied. The wording used was "spark-over measurements which may be roughly described as follows. . . . The formative time in domain 2 must, therefore, allow for positive ion migration."

Specifically, as Mason states, the available positive ion mobility measurements, besides being uncertain by a factor possibly as large as 5, are obtained by measurements at conditions decidedly different in many ways from those prevailing at spark-over at atmospheric conditions. His extrapolation from mobility measurements made at from $x/p = 36$ to $x/p = 79$ at the test gap would be open to question even if the spark could be assumed to be nowise different from undisturbed air. In view of the fact that it hardly can be questioned that something in the spark gap is violently different at the sparking voltage than at voltages just below, it seems a bit hazardous to extrapolate into the sparking condition with such a leap. If, however, from such considerations one makes a rough estimate of the probable mobility of the positive ion in the gap at the *normal* test gap field strength, it is true that the estimated time of transit is distinctly less than the formative lag observed in these measurements.

This raises 2 interesting questions. First, how is the observed formative time to be exactly accounted for? The answer given here is, of course, speculative and only one of several possibilities. At the lowest sparking voltages, particularly in a very short gap, it may be necessary that the concentration of voltage drop at the cathode be culminated by the rearmost positive ions approaching the cathode. Throughout their travel these ions have the major portion of the space charge, and also, therefore, of the voltage drop, before them. During their travel a very small fraction of the voltage drop occurs in the major length of the gap far from the cathode. So these, the last positive ions whose travel is necessary to complete sufficiently the space charge concentration near the cathode, move in a field much weaker than the nominal field present and, therefore, move much more slowly. It is also possible that a cumulative succession of passages of positive ion clouds across the gap may be required.

Secondly, if the observed formative time lag did differ from the true time of transit of the positive space charge, would this invalidate the division of the formative lags into those involving primarily electron travel and those involving primarily positive ion travel? This question may be answered confidently in the negative. In the first place, it is generally agreed that spark-over is a cumulative process culminating in a highly ionized gap with a highly distorted field. Mason assumes that any sparking mechanism involving positive space charge migrations occurs simply in the time required for the transit of a single isolated ion across an un-ionized gap. This assumption is, perhaps, quite justifiable as an initial approximation in the absence of other knowledge. It is hardly an inviolable principle by which to reject experimental fact.

The growing body of spark lag measurements, moreover, combines to indicate that the spark-over mechanism varies most widely as the overvoltage is progressively altered. Formative spark lags have been observed ranging from those here presented, longer than the apparent time of positive ion transit, to intervals shorter than the apparent time required for electrons to cross a fiftieth of the gap length.[19] It has been the practice throughout to correlate these various formative times in a general way with the not exactly known travel time of electrons or positive ions. Such correlation over this time range is meaningful only if we assume shifting mobilities or shifting spark mechanisms, or both, as the overvoltage is varied. Though details remain to be observed, such a shift is fully indicated. The formative time is concerned with positive ion travel and/or with electron travel, which is some thousand times as rapid. A formative spark lag of 7×10^{-6} seconds does involve a different spark mechanism than a lag of 3×10^{-8} seconds. Considering the tremendous spread of the time range concerned, the formative time lags here presented can fairly be said to fall within the general order of time of positive ion migration.

It still appears, as originally stated, that the time lags divide unequivocally into 3 domains: first, random initiatory lags; second, relatively long formative lags occupied with positive ion space charge migration; third, the very short formative lags of electron travel. The distinction between the last 2 spark mechanisms is substantiated by the direct visual observations of Dunnington and others, as pointed out in the paper.

The use of a cathode ray oscillograph as a check and supplement to the apparatus

utilized would be most advantageous. This is particularly true as regards the wave shape and general adjustment of the voltage producing apparatus. An oscillographic check of the time reading would also be of interest. It is to be regretted that a suitable cathode ray oscillograph was not available. A direct experimental check of the time calibration of the instrument was made, however. Using a capacitor, resistor, and inductor of known value, the capacitor was charged to a definite overvoltage and then discharged through the other units in a simple series circuit. The time of discharge down to the 100 per cent voltage setting was computed from the fundamental equations of the simple series curcuit and the computed time checked against the measured. By means of a series of such transients the intrument was checked over a wide time range. The check was within 4 per cent throughout.

In conclusion, I can agree heartily with Mason that further measurements of these and related items will be most useful. I am particularly pleased to see the recent article by Nord[18] as a step in the right direction.

The following 4 references are in addition to the 17 references given in the paper:

18. Effect of Ultraviolet on Breakdown Voltage, G. L. Nord. Elec. Engg. (A.I.E.E. Trans.) v. 54, Sept. 1935, p. 955–8.

19. A Study of Short Time Lags in Sparks as a Function of Overvoltage, R. L. Wilson. A paper presented before the American Physical Society at its meeting of December 21, 1935.

20. W. O. Schumann, *Elektrotechnik und Maschinenbau*, v. 24, 1933, p. 3333.

21. Über die Entwicklung der Raumladung einer Funkenstrecke bei Stossponung, Sämmer. *Zeitschrift für Physik*, v. 81, 1933, p. 383–404.

The Sparkless Sphere Gap Voltmeter

Discussion and authors' closure of a paper by R. W. Sorensen, J. E. Hobson, and Simon Ramo published in the June 1935 issue, pages 651–6, and presented for oral discussion at the electrophysics and measurements session of the Pacific Coast convention, Seattle, Wash., August 29, 1935. This paper was also presented at the summer convention, Ithaca, N. Y., June 27, 1935, and other discussion was published in the September 1935 issue, pages 1002–4.

E. A. Schuchard (University of Washington, Seattle): The authors are to be commended on their valuable addition to the subject of potential measurements. This new method of using the sphere gap seems to avoid most of the objections to the spark-over method. However, there are a few points in the paper on which the authors' comments are desired.

1. No mention is made in the paper concerning the effect of the necessary supporting structure of the spheres on the force between the spheres. From the photographs given of the instrument, the mounting of the fixed sphere seems rather large and near the actuating field. It would be interesting to know how the authors arrived at the conclusion that this effect could be safely neglected in the theoretical calculation of the forces and what order of error is involved in such a neglect at various spacings.

2. It is rather surprising that the effect ground planes is as small as described in the paper. What were the size and spacings of the test planes used and were any tests of this type made above 30 centimeters spacing for the 100 centimeter spheres? Also, the reasons for the particular choice of ground planes used in the theoretical approximation of this effect are not perfectly clear. Were the other walls of the laboratory so far away in comparison to the 2 employed as to be of minor importance?

3. The authors make a statement on page 655 concerning the excellent agreement of their curve A of figure 4 with Meador's figure 8. Perhaps it should be pointed out that this statement is restricted to sphere gap settings below 30 centimeters; for a comparison with the values given by Meador in his table IV for 100 centimeter spheres and 60 cycle spark-over indicates an upward divergence of the authors' results above those of Meador's for larger than 30 centimeters spacing amounting to almost 4 per cent at 60 centimeters spacing. Without more knowledge concerning the actual test conditions, this order of deviation seems to be larger than found in other recent investigations (see the discussions of Meador's paper "Calibration of the Sphere Gap," Elec. Engg., v. 53, Dec. 1934, p. 1652–60, particularly tables I, III, and V) and might be attributed to factors of the type mentioned in the first 2 points of this discussion, especially since at the larger spacings these factors are of more significance. If such is the explanation, a more extensive investigation of these points appears to be necessary before the sparkless sphere gap voltmeter will have maximum promise and range as an absolute instrument.

4. The method of using this instrument has been, apparently, to vary the sphere gap spacing until maximum force without spark-over was obtained. This procedure gives maximum accuracy but requires the precise measurement of 2 variables, force and distance, for each separate voltage measurement. It is wondered if such an arrangement does not make successive voltage measurements a slow and tedious process. If not, a convenient, rapid, an accurate means of making spacing adjustments must have been devised. Remembering the Kelvin absolute attracted disk electrometer, the foregoing surmise naturally brings up the next point.

5. Might not keeping the balancing force constant at a suitable value and adjusting the sphere gap spacing to obtain a balance have possibilities as a measuring technique with this instrument? Perhaps the reasons for this question need further elaboration. The equation of the instrument is

$$V = 9405\sqrt{F/S} \tag{1}$$

where V is the effective value of the applied potential in volts, F is the resulting force acting on the spheres in grams, and S is the spacing factor having the variation with sphere gap spacing shown in figure 8 of the paper. (It might be noted that the abscissa scale of figure 8 might just as well have been labeled sphere gap spacing in per cent sphere diameter. Then the curve would be applicable to any pair of isolated equal-diameter spheres regardless of size.) From equation 1 it may be seen that with constant spacing a square-type relation exists between potential and force. Therefore, constant spacing would not produce a desirable type of scale characteristic for this voltmeter. With force maintained constant, however, the potential is proportional to $1/\sqrt{S}$ which quantity proves to have a quite linear variation with gap spacing except at the smaller distances. In fact, a rough calculation and graphing indicated to the writer that $1/\sqrt{S}$ could be given by the equation

$$1/\sqrt{S} = 0.0606\,D + 0.860 \tag{2}$$

where D is the gap spacing in per cent sphere diameter, to within less than 1 per cent over the range from 20 to 100 per cent sphere diameter spacing. Thus, keeping the force constant should produce a more desirable type of scale. Furthermore, it would seem that the spacing of the spheres could be made to operate a visual-reading scale and that the instrument could be made continuous reading, following moderate changes in voltage, by having the spacing mechanism automatically controlled to hold the constant balancing force in equilibrium. Different restraining forces could be used for different voltage ranges or sensitivities, scale readings being corrected by a constant factor known from the force used. It is unfortunate that this method of use is most convenient in the range over which the assumption of perfectly isolated spheres does not appear to be permissible. However, if by any means the relation between $1/\sqrt{S}$ and gap spacing is determined for a given set-up, then the instrument is completely calibrated regardless of the particular balancing force (i. e., sensitivity) being used.

The writer's interest in high potential measurements arose through studies on the "rotary" or "generating" voltmeter made during the past 2 years at the electrical engineering department of the University of Washington (see "The Generating Electrostatic Voltmeter" by E. A. Schuchard, Bulletin No. 80 of the University of Washington Engineering Experiment Station, April 1935). As the generating voltmeter has much the same field of application as this sparkless sphere gap voltmeter, perhaps a comparison is appropriate. The sphere gap instrument is applicable to any frequency, indicating the effective value regardless of voltage wave shape; while the generating voltmeter is limited by mechanical considerations to relatively low frequencies—probably not greater than several thousand cycles per second. However, the generating voltmeter has the characteristic of measuring just a single point on the voltage wave, and since this point can be made any desired, it has the distinctive advantage of being able to determine directly, in a point to point manner, the high potential wave shape. As far as being an absolute instrument, both voltmeters are about equally promising. The generating voltmeter's calibration, which is linear, depends upon a capacitance value which by suitable instrument design should be calculable just as readily as the forces in this paper. The generating voltmeter is unquestionably very convenient to use, especially in moderately high, steady-state voltage measurements. However, the greatest practical objection or disadvantage to the

generating voltmeter is that its readings are apt to be meaningless or misleading if excessive corona is present in the high potential field. Such an instance may occur around a Van de Graaff high voltage generator as described in "High Voltage Technique for Nuclear Physics Studies" by M. A. Tuve, L. R. Hafstad, and O. Dahl (*Phys. Rev.*, v. 48, Aug. 15, 1935, p. 315–38). Probably this sparkless sphere gap voltmeter is subject to similar limitations.

Abe Tilles (University of California, Berkeley): It would seem that the sparking sphere gap is on trial for its life. The indictment was drawn up some years ago in reference 1 of the paper. As has been pointed out, there may be some doubt whether air as a sparking material may rightly be considered as a primary standard of reference. Accordingly an instrument, such as the one described in this paper, capable of measuring an individual voltage with surety is most welcome. Furthermore, the electrostatic attraction is a sufficiently stable and basic phenomenon that it may well be used as a primary standard of voltage. Wherever the root mean square voltage measurement is adequate, the instrument described appears destined to replace the spark gap as a primary standard.

For measuring peak voltages directly, however, this instrument as it stands does not seem ideal. To measure the peak, or in fact the entire wave shape, of any *steady state* wave the rotary voltmeter described by J. E. Henderson, W. H. Goss, and J. E. Rose ("The Use of the Rotary Voltmeter for Measurements Up to 132 Kilovolts," *Rev. Scien. Instr.*, v. 6, Mar. 1935, p. 63–5) possesses definite advantages over any other device. It will not, however, measure the peak of an individual voltage wave. All this brings us back to the fact that the spark gap, while very much under fire, has still a definite field of usefulness. Its advantages may be listed as follows:

1. It responds to the *peak* of an individual voltage rise.
2. It is a sparking measurement involving the same phenomenon as spark-over of insulation.
3. Satisfactory commercial accuracy has been achieved.
4. Further increase in accuracy appears attainable.

In regard to test accuracy, we must remember that some of the errors attributed to the sphere gap are more justly charged to initial inexperience with ultra-high voltage equipment generally. In particular, it should be noticed that the measurements of Meader (reference 5 of the paper), of Bellaschi and McAuley ("Impulse Calibration of Sphere Gaps," P. L. Bellaschi and P. R. McAvley, *Elec. Jl.*, v. 31, June 1934, p. 228–32) and of Henderson, Goss, and Rose agree with each other much better than with Peak's extrapolations, as incorporated in the present A.I.E.E. Standard No. 4. Each of these measurements initially, because of its disagreement with the institute Standard, tended somewhat to discredit the sphere gap. Taken altogether, however, they indicate clearly that an accuracy of some 3 per cent is at present attainable from the spark gap at the highest voltages tried.

Furthermore, as indicated in the writer's paper on "Spark Lag of the Sphere Gap" (Elec. Engg., v. 54, Aug. 1935, p. 868–76) we may look forward to further increase in accuracy when one of the known sources of error is brought under control by controlling the time lag.

It is evident from the time lag measurements, and from the polarity characteristics given by Meader and others, that the character of the spark changes as the gap length is changed. Such indications are difficult to interpret, however, since they depend on the highly self-accelerating spark-over process, which greatly exaggerates any initial difference. Figure 9 of this paper, however, if replotted against gap length, gives a plot of difference in initial conditions *at the commencement of spark-over.* Further study of such plots for the various sphere sizes should provide an insight into the variation in kind of spark-over as the gap length is altered.

R. W. Sorensen, J. E. Hobson, and **Simon Ramo:** The authors presented this paper with the object of calling attention to the method and its possibilities. Further work, both experimental and theoretical, is being done at the present time to check more closely the characteristics of the instrument which were observed in this first preliminary study and to evaluate quantitatively its accuracy throughout its measuring range.

The discussions have brought up several points which truly require close investigation before the meter may or may not be termed an absolute instrument. Some additional information which was not presented in the paper may serve to answer some of these questions.

1. Experiments were performed to find the effect on the force of extraneous bodies in the laboratory at high potential; such as the transformers themselves. At 30 centimeters spacing, with transformer voltage constant, the force dropped from about 350 to 5 grams when the high potential sphere was disconnected but insulated, and to 1 gram when the high potential sphere was grounded. At 40 centimeters spacing, the force dropped from about 200 grams to 5 grams when the high potential sphere was disconnected but insulated, and to 1 gram when the high potential sphere was grounded.

2. A wooden tower with a platform about 6 feet square and tall enough to be within about 3 feet of the surface of the spheres was placed directly under the high potential sphere, then directly under the gap, then directly under the grounded sphere with no observable effect on the force at constant voltage. This was done at 40 centimeters spacing.

3. A grounded plane about 6 feet square was moved to various positions about the gap at 25 centimeters spacing. With voltage constant, the force was 201 grams when the plane was 15 feet from the center of the gap; 197 grams when facing the center of the gap and about 7 feet away; 200 grams when 7 feet behind the grounded sphere; 198 grams when 7 feet behind the high potential sphere. It is not too surprising that the observed effect of this ground plane was so small, for it must be remembered that a mere distortion of field does not necessarily entail a change in force of the same degree. Force is proportional to the integral of field intensity squared over the entire surface of the moving sphere. It is then quite possible that the proximity of a plane or other object, though it change capacitance and consequently charge on the spheres, might also change the distribution to the extent that the net change in force might be very small. Now, quantitative comparisons of the contributions to the total force of various portions of the spheres' surfaces have not yet been made. But it is known that the contribution due to force lines ending on the back of the spheres becomes a decreasingly small part of the total force as the gap spacing is decreased. That at 25 or 30 centimeters we have reached the region where the field behind the spheres is so weak compared to that at the center that a distortion of this weak field by a small plane or shank results in a very small change in force seems to be indicated by these experiments.

4. The theoretical calculations for an end wall and the floor of the laboratory were mentioned in the paper to point out that the method of images could be used to calculate the effect on the force between 2 isolated spheres of ground planes in the 2 positions that normally would be met in a laboratory: a plane perpendicular to the line of centers and one parallel to the line of centers. In fact, one might compute by this method the effect of an entire box-like enclosure about the spheres if he but had a large enough sheet of paper and sufficient patience to consider the huge number of images necessary to give accuracy. The 2 closest planes in our laboratory were the floor and an end wall and the computations described in the paper for 25 centimeters are believed to give order of magnitude of the effect of each separately and no more. Very rough computations (considering only principal images) were made for spacings up to 100 centimeters. This data was considered too undependable for publication but the results showed errors of only several per cent even at the highest spacings and added further indication that the effect is very small at low spacings.

5. The effect of the walls, ceiling, and floor of the laboratory is to decrease the force for any given voltage. This follows both from image calculations and from investigations being made with a model of the spheres and laboratory to about $^1/_8$ scale. In this model, which was set up to provide results more easily than they could be computed, walls, ceiling, etc., are removable so that their influence is directly observable. However, a consideration of the electrostatic field shows that the addition of shanks to the spheres should increase the force for any given voltage. Thus, these 2 effects, which are probably small in themselves at the lower spacings, tend to neutralize each other.

Disagreement between the spark-over curve of the authors and that of Meador at larger spacings is of the order to be expected on the basis of the change of spark-over curve with gap position according to data presented by Meador in the previous discussion of our paper.

A self-balancing scheme as suggested by E. A. Schuchard, or a similar one that would change force rather than spacing, would certainly represent an improved measuring technique. The way in which the meter is to be used most conveniently with accuracy will depend on what is to be measured as well as the elegance of the measuring mechanism. In the case described by the authors, a spark-over reading was desired for the same spheres between which the force of attraction was to be measured, so that gap distance had to be varied and measured over the whole range. For our set-up it was very much easier to balance at a known spacing by adding or subtracting from the balancing force than it would have been to move the high potential sphere back and forth until balance was secured.

Diesel Electric Motive Power for Railroads

Discussion and author's closure of a paper by A. H. Candee published in the August 1935 issue, pages 863–8, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Seattle, Wash., August 30, 1935.

G. H. Walker (Great Northern Railway Company, Seattle, Wash.): The question is asked frequently: "Will the development of Diesel electric motive power for railroads retard or supplant railroad electrification?" Perhaps there is a tendency to retard electrification, as the possibility of development

of a motive power unit having some of the advantages of the electric locomotive without the necessity of the heavy investment in power conversion and distribution is intriguing. However, the author brings out clearly that as at present developed the Diesel engine cannot compete in the field of the electric locomotive where heavy traffic is required to be handled at high speeds or on heavy grades; in other words, road hauls demanding large power over long distances.

In my opinion, though, the Diesel has an important field as a supplement to the electric locomotive in an electrification project, as a switching and transfer unit to operate on industry spurs and yard trackage where for economical or other reasons electrification of these tracks is not desirable. In transfer and local freight work involving considerable switching at the terminal and intermediate points, a combination unit, such as developed on the New York Central Railroad, using power from the third rail, storage battery, or Diesel engine makes a very desirable unit as it extends the zone over which the advantages of the unit can be obtained.

Candee's comments on the development of high speed streamlined trains are interesting and well taken. Worth-while economies can be realized by reduction in weight of railroad equipment, but the railroads have on their hands much serviceable equipment of the heavier type which they must continue to use, but which is beyond the capacity of the Diesel locomotive to handle, leaving the field to the steam locomotive or to the straight electric locomotive where the traffic is heavy enough to justify electrification.

Sidney Withington (New York, New Haven, and Hartford Railroad, New Haven, Conn.): This paper is of much interest, since the problem of increased economy is, perhaps, one of the most vital in the railroad field today. The use of Diesel motive power is still relatively young, and reliable operating data as yet are quite incomplete. Variations are exceedingly wide under varying conditions of operation and general figures are, therefore, somewhat dangerous. Nevertheless, any analysis by a man of rich experience and marked ability who is familiar with the latest developments in Diesel motive power, as is the author, is of timely interest.

He presents a typical cost comparison between a steam locomotive with a passenger train, presumably of 2 cars, as against a Diesel motorcar with a trailer, to handle the same service. The steam train investment is given as $42,000, while that of the Diesel train is $81,000. Such figures, while perhaps accurate as regards relative costs, cannot, as a rule, be strictly compared, because in most situations of the type under discussion, the railroad would already have available for the service steam equipment which otherwise would not be used. Were such equipment replaced by Diesel facilities, as suggested, new cash would be required and the *entire* capital costs for Diesel power should be chargeable against the new equipment, without reference to money already invested in existing equipment.

Motive power repairs are given in table I of the paper as $0.0440 for the Diesel equipment and $0.2791 for the steam locomotive equipment. This ratio of more than 6 times the cost for steam equipment seems high, and, while it may be correct in some individual instance, it is doubtful whether it is justified by normal operating experience. The expense for water on the steam equipment of about 25 per cent of the fuel cost seems high, and perhaps would not be experienced except under special conditions.

The engine house expense, given as about $0.10 per mile for steam and $0.012 per mile for Diesel power, may be experienced under certain circumstances, but in general the superimposition of a few units of Diesel power upon a steam locomotive terminal would reduce but very slightly the annual terminal expenses, and while the actual labor of "turning" the Diesel train may be small, it would not be fair to assign any considerable credit if many of the fixed expenses incident to the operation of the steam terminal cannot be reduced.

The depreciation on the Diesel train equipment, as set forth in table I, amounting to approximately 2.9 per cent, is too low, all things considered.

Referring to table II, which deals with switching service, while in certain cases it may be possible to eliminate the fireman from a Diesel locomotive, just as in certain cases it may be possible in the passenger service as the author has discussed, nevertheless, in many instances, either on account of the yard arrangement or on account of local ordinances, it may be necessary to retain the fireman, even with Diesel locomotive operation.

The expense for water, mentioned in table II, in the steam locomotive column seems relatively high. The relative cost of repairs, noted as about $14 per day for Diesel and about $54 for steam locomotives, does not seem justified by normal operating experience. In this case also, the engine house expense ratio of $2 for the Diesel and $7 for steam would probably not be realized under normal circumstances as representing a definite over-all economy.

The depreciation, given as $7.20 per day for the Diesel locomotive which, apparently amounts to 4.2 per cent of the investment annually, is somewhat low.

In discussing steam locomotive repairs the author says that the unit cost definitely rises during the life of the locomotive. This is open to a great deal of question. While it is true that there may be some increases in maintenance expense per mile on the occasion of various classes of repairs, there is no doubt that as the classified repair cycle recurs and the mileage accumulates, the expenses, in the long run, rather definitely approach a horizontal line.

The economies in Diesel operation are, other things being equal, a function of the operating flexibility of the unit and the mileage which can be made during the year. As Candee says, Diesel switching equipment is often not available for transfer service where the greater steam locomotive horsepower can be used to advantage. If, therefore, there are double service requirements, as is very often the case in a switching yard, where the switcher may be required to perform certain road service, the economies expected from the Diesel unit may be seriously affected. This may also be true in the typical passenger service analysis which Candee presents, where, in the interval between passenger train trips, a steam locomotive may be available to do a certain amount of freight transfer service or switching.

The author states that there are only 2 commercial sources of railroad motive power available, steam and the internal combustion engine. He apparently does not have in mind the functions performed by railroad electrification. Many very difficult problems have been solved by electric locomotives and cars in various parts of the country.

It is intimated that the first cost of Diesel motive power is high under present conditions. This factor is undoubtedly the greatest limitation of the Diesel equipment. It is to be hoped that with a growing demand for that very efficient type of motive power, the construction costs will be very materially reduced by standardization of design and by applying quantity production methods, and that the railroads may, before long, obtain the very real advantages made possible by the Diesel engine. Meanwhile, very careful analysis is necessary to insure that the development is not retarded by faulty or uneconomical application in individual instances.

A. M. Wright (Reading Terminal, Philadelphia, Pa.): The author cites table I as a typical example of savings resulting from a replacement of a steam train by a Diesel electric motorcar and trailer. It may be taken equally well as a typical example of extravagant railroading. The figures quoted apparently apply to a steam locomotive of 2,200 horsepower hauling 2 cars, in service where the schedule requires about 3 horsepower per ton of total train weight.

A comparison of the steam train figures in table I with corresponding average figures for a 2,200 horsepower locomotive in main line passenger service is as follows, all costs being per train mile:

	Table I	2,200 Horsepower Locomotive
Motive power repairs	$0.2791	$0.28
Fuel	0.1036	0.28
Water, lubricants, supplies, and engine house expense	0.1411	0.16

When a 200 ton locomotive hauls 2 coaches, the available horsepower per ton is about 7.3, whereas the service specified in table I requires only 3, so that the fuel cost in table I is lower in about this ratio than that given here for main line service. I do not believe there are many railways on which steam locomotives are used so extravagantly as the author assumes. Light passenger service undoubtedly constitutes a large field for Diesel electric traction, but its proponents would do well to avoid making the story too good. However, the total depreciation of the Diesel electric equipment is shown in table I to be about twice that of the steam equipment, and the total investment for the steam train is shown at about half that of the Diesel electric train. Evidently the steam locomotive is considered to be so old that it

cannot depreciate much further; a new 2,200 horsepower steam locomotive and 2 coaches would cost about $125,000, instead of $42,707.

Table II is also quite unsatisfactory. For example, the repair cost per day for a 900 horsepower steam switcher is given as $54.48. This amounts to about $20,000 per annum, and a railroad running such expensive engines would certainly be tempted to adopt Diesel electric locomotives. However, a reference to figure 8 shows the annual repair cost for 20 year old steam switching locomotives to be about $2.50 per horsepower. On the basis of 4,000 hours work per year, a 900 horsepower engine would then cost about $0.56 per hour for repairs, or $13.40 for a 24 hour day. On the author's method of calculation, then, the saving due to repair cost entirely disappears, and instead of 40 per cent, the return on the investment becomes about 16 1/2 per cent. However, the tabulation in the paper has little value, since it assumes 24 hour per day operation for 365 days in the year, which of course is never attained either with steam or Diesel electric engines. Table II entirely ignores one of the greatest advantages of the Diesel electric switcher, which is its high degree of availability. The costs should be on an hourly basis, and the availability can then be taken care of in figuring annual costs.

The repair costs shown in figure 8 seem rather low; the maintenance cost of steam switchers may be taken fairly at something approaching twice that shown in the curve.

The author says that the useful tractive force of electrically driven driving wheels may be 20 or 30 per cent higher than that of steam locomotives; in another place he speaks of it being 50 per cent higher, and attributes this to the uniform torque of the electric motor. The steam locomotive has a tremendous advantage, however, in its coupled wheels. A rail is not continuously slippery, but has slippery spots, which may be so pronounced as to become quite well known to the operators. A pair of wheels on a steam locomotive has less chance of slipping on one of these spots than the uncoupled wheels of an electric locomotive. Slipping with electric drive is particularly pronounced at low speeds when the motors are in series. In that case, if one motor begins to slip, its counter electromotive force immediately rises and in order to maintain the relation $V = E - RI$, it is clear that V also rises. Consequently the slipping wheel continues to slip at an increasing rate, while the tractive effort exerted by the nonslipping wheel falls to zero. For these reasons I believe it is not safe to figure on an adhesion of more than 30 per cent with electric drive under the best conditions, which is only about from 13 to 20 per cent higher than the values easily obtained with steam locomotives.

It is interesting to read a paper in which it is admitted that the light weight construction of the new high speed passenger trains has made the Diesel electric drive possible in main line service, instead of urging the usual claim that it is the Diesel engine which has made the high speeds possible. Of course the whole matter reduces to that of horsepower per ton of total train weight, and following that to its logical conclusion, it appears that from a physical standpoint the correct equipment for high speeds is the straight electric. In suburban service particularly, the light weight equipment is in a position to make an important contribution to railway electrification, since with its use the energy consumption becomes so much lower for a given schedule as to realize important savings in the expensive distribution system. For this reason railway electrification becomes economically feasible in many instances where other wise the traffic density would not justify it.

A. H. Candee: G. H. Walker's remarks need no comment, although it is not agreed that a storage battery is an economical source of motive power for railroad switching, even when used in conjunction with a Diesel engine. If extra power is needed for fast accelerations (as with the existing combination storage battery-Diesel units), it is better to apply additional Diesel engine power in place of the battery. In connection with the modern light weight unit train, it is fully recognized that the railroads of this country have so many serviceable cars of the former standard design and weight that it is obviously out of the question to retire this rolling stock prematurely. However, it will undoubtedly be found that normal replacements will be made with lighter equipment and thus there will be a gradual decrease in train weights over the next 20 to 30 years. Even now Diesel motorcars of standard construction are in service, capable of hauling 6 or 7 conventional trailers on steam train schedules.

A. M. Wright's remarks indicate considerable skepticism as to the operating cost figures used in tables I and II. Actually, the results of a great many studies on different railroads indicate that the costs used in table I are typical. As a matter of fact, these steam costs were obtained directly from a railroad and have not been altered in the slightest degree. Overstatement of Diesel economies is undesirable and actual comparisons of a typical nature should always be presented.

In the depreciation shown by table I, Wright has pointed out that the Diesel equipment would make even better showings if compared to new steam equipment, as the steam depreciation figure would then be considerably higher than as given by the table. However, the old steam equipment was actually in service on this run and was being depreciated as shown, so that no increase in the steam depreciation charge should be considered.

The costs as given by table II are for a fairly large yard where there are from 7 to 10 locomotives working at all times. The 24 hours per day and 365 days per year are for an "active" locomotive, to accomplish which the steam operation must be served by approximately 1.6 locomotives, and the Diesel operation by 1.12 locomotives per "active" locomotive. The spares (both steam and Diesel) are accounted for by an increase in fixed charges per "active" locomotive over those which would be used if but one locomotive were employed for this 24 hour per day service.

In regard to the maintenance expense of the steam locomotives, reference to tabulated costs issued by the American Railway Association in the 1932 report of the Committee on Locomotive Construction show many instances of costs exceeding $2.27 per hour ($54.48 per day). If the normal repair expense rises as the locomotive age advances, as has been claimed from a study of thousands of locomotives, then the $2.27 per hour does not appear to be out of line over an ensuing period of years, which is the only fair basis of making comparisons.

In reference to the higher starting tractive effort of electric motor driven wheels, this is normally 20 per cent to 30 per cent higher than for steam with the same weight on drivers. The example used (50 per cent higher than for steam) is for a Diesel locomotive of greater weight than the steam unit.

Wright apparently advocates electrification in place of Diesel equipment. There is no doubt but that the most economical motive power for dense traffic zones is electricity, but for the majority of places where Diesels may be used, electrification is out of the question.

Sidney Withington points out that variations are exceedingly wide under general conditions of operation. That this is the case and that direct comparisons should not be taken too seriously unless the complete background of operation is known is agreed. The particular cost figures shown by table I were received directly from the railroad itself. In this case, the railroad was in a position to transfer the steam equipment to another location, thereby resulting in the retirement of equipment at that other location which had been completely depreciated. Incidentally, a great many such studies and actual substitutions have shown the same conditions to exist.

The steam costs used in table I are, as stated previously, the exact figures given by the railroad. The Diesel costs include overhaul expense. The Diesel costs, however, include no maintenance expense for the car body, as this is included under car repairs. It must be admitted that the water expense is high, but this is a relatively small percentage of the total cost, and water treating probably accounts for some of this high expense. Referring to enginehouse expense, the relative figures used by the railroad are sufficiently close to similar figures found in many other cases that they have been assumed to be typical.

Withington points out that the depreciation rate used in table I is too low (2.9 per cent). Railroads normally use a rate varying between 3 per cent and 5 per cent.

It is agreed that yard locomotive firemen may not always be eliminated, although it is desirable to do so wherever possible. As pointed out previously, all costs shown are the railroad's own figures.

Withington expresses a very interesting point of view in regard to locomotive repair expense trends. A great many articles have been written around this subject, and while the straight line trend curve has been rather generally adopted, there is still an element of doubt as to its accuracy. It might be suggested that a full exposition of his ideas on this subject would be very timely.

That electrification serves the railroads well for the solving of many difficult operating problems is agreed. However, electrification has not been considered as a "mobile" source of motive power (as mentioned in the paper) because electric locomotives are limited to operating zones provided with an electric distribution system.

News

Of Institute and Related Activities

The 1936 Winter Convention Best Attended Since 1932

WITH a total of 1,231 members and guests, registration at the Institute's 1936 winter convention held at the Engineering Societies Building in New York, N. Y., January 28–31, was the greatest at any winter convention since 1932. An all-time record was established of 342 railroad certificates validated, which means that the attendance from out of town was better than usual. Details regarding the registration figures are given in accompanying tabulations. Attendance at the various technical sessions and the other attractions and entertainment features of the convention was uniformly good.

A special feature that could not be given the benefit of advance notice was an account of the disturbance occurring on January 15, 1936, on the New York Edison system, which had aroused widespread interest. This was given on the morning of January 29, immediately preceding the technical sessions, by H. C. Forbes (A'25, M'30) system engineer of the New York Edison Company. Mr. Forbes's remarks are recorded elsewhere in this issue.

The convention included the usual social and entertainment features, a brief report of which is given in the following paragraphs. Reports of the major events will be found on succeeding pages in this issue.

Mascart Medal Award to Dr. Kennelly Announced at Opening Session

A feature of the opening session of the convention was the announcement of the award of the Mascart Medal to Dr. Arthur E. Kennelly (A'88, HM'33, life member, and past-president) professor emeritus of electrical engineering, Harvard University and Massachusetts Institute of Technology, Cambridge. After C. R. Beardsley (A'08, F'30) chairman of the winter convention committee, had extended a hearty welcome to those attending the convention, A. M. MacCutcheon (A'12, F'26, and nominee for president) chairman of the Lamme Medal committee, made formal announcement of the award to Doctor Kennelly and outlined a few facts concerning it. He said that the award was established in 1923 in memory of one of the founders of the Société Française des Électriciens, and that it is awarded triennially to "a scholar or an engineer, French or foreign, member or nonmember of the Société, who has distinguished himself by his contributions to applied science." Thus, the award is international in its significance. "It is a signal honor to America, and to the A.I.E.E.," Mr. MacCutcheon concluded, "that Doctor Kennelly's name is now added to the distinguished group to whom the medal has been awarded."

In his response, Doctor Kennelly, with his characteristic modesty, said that he considered some others far more worthy of the honor than himself. He expressed the hope that the award might be regarded as a token of liaison between French and American scientists and engineers, and that American engineers might soon bestow a similar honor upon some foreign engineer.

Following Doctor Kennelly's remarks Mr. Beardsley introduced President E. B. Meyer who expressed his pleasure at seeing so many familiar faces in attendance at the opening session.

"It is the natural desire of the Institute officers to make these gatherings attractive to the entire membership," he said. "We want them to serve as common ground, where mutual problems can be discussed and a friendly spirit of co-operation fostered, so that each member may take away a broader understanding and a greater professional feeling.

"The foundation of the Institute's strength lies in its technical activities, namely, the technical committee work, standards, publication of technical papers, and meetings and discussions for all members. The technical sessions and conferences of this meeting have been scheduled to bring forth a number of developments in specialized fields, and several of the papers to be presented at these sessions are of international importance.

"It is significant that during these times the members of our profession continue to carry on research to find more efficient ways to utilize the materials and the forces with which they work. This constant application of effort toward improvement is a sign of a sound, healthy condition. The members of the electrical engineering profession have been doing highly effective work in spite of unfavorable economic conditions and reduced appropriations and there is no doubt that this activity will yield an enormous return.

"We can be justly proud of the great engineering progress made, particularly over the past few years, and the future will depend on how we, ourselves, carry on, not only as individuals but through the sound policies established by the Institute that have been responsible for its remarkable growth and expansion."

Following President Meyer's brief address, W. R. Smith (M'18, F'30) chairman of the technical program committee, spoke briefly regarding the technical sessions to be held during the convention, emphasizing some of the special features. He said that the technical sessions had been planned by many minds and hands, and expressed the thanks of the technical program committee to the chairmen of the technical committees through whose efforts the sessions had been organized. He called attention briefly to the rules for presenting and discussing papers, and voiced a plea for good attendance as the success of the various sessions depends as much on the audiences as upon the papers to be presented.

Analysis of Registration at Recent Winter Conventions

District	1934	1935	1936
New York City and Foreign (3)	812	694	697
North Eastern (1)	179	194	219
Middle Eastern (2)	161	153	222
Great Lakes (5)	40	38	43
Canada (10)	16	21	11
South West (7)	11	5	11
Southern (4)	5	6	15
North Central (6)	2	1	6
Pacific (8)	1	1	4
North Western (9)	0	1	3
Totals	1,227	1,114	1,231

Out-of-Town Registration at Recent Winter Conventions

Year	Total Registration	% Registration From Dist. 3*	% Registration From Outside Dist. 3*
1932	1,429	63	37
1933	1,099	72	28
1934	1,227	66	34
1935	1,114	62	38
1936	1,231	57	43

* New York City and foreign

Technical Sessions

With the exception of the session on welding, no report of the technical sessions will be given here, since all papers discussed have been published previously in Elec-

trical Engineering, and since such discussions of these papers as are recommended for publication by the A.I.E.E. technical program committee will appear in future issues. All sessions were accompanied by interesting and pertinent discussions; those on power transmission, magnetic materials, and modernization of distribution systems attracted the greatest attendance and consequently were featured by the widest discussion.

Session on Electric Welding

Demonstrations of welding equipment and the showing of high speed motion pictures depicting welding phenomena featured the session on electric welding held on Thursday afternoon, January 30, under the auspices of the committee on electric welding with H. M. Hobart (A'94, F'12, and member for life) chairman of the committee, presiding.

After opening the session Mr. Hobart called on Prof. C. A. Adams (A'94, F'13, member for life, and past-president) Lawrence professor of engineering, Harvard Engineering School, Cambridge, Mass., who spoke briefly on welding research. He said that when he entered the welding field, research was being carried on in many places throughout the United States in a somewhat haphazard fashion and with little co-ordination between various projects. At that time, he said, but few well qualified research workers were available. Speaking of the American Welding Society, Professor Adams said that this society had accomplished more in research in the first few years of existence than had any of the other leading engineering societies in their respective fields. At the present time he said that 80 research projects in welding are now being carried on under sponsorship of that society. Many of these projects are being carried on jointly by the American Welding Society and the A.I.E.E., with the aid of Engineering Foundation.

Following Professor Adams' remarks, J. W. Dawson (M'35) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., demonstrated the accuracy of that company's vacuum tube apparatus for controlling the welding current for spot and seam welding. This was done with the aid of equipment developed for commercial use, and the accuracy of control was portrayed on the screen of a cathode ray oscillograph. A period of informal discussion followed the demonstration, in which some of the basic features of this method of control were brought out.

Next on the program was the showing of high speed motion pictures by W. E. Crawford (M'28) of the A. O. Smith Corporation, Milwaukee, Wis., and by H. A. Winne (A'16) of the General Electric Company, Schenectady, N. Y. These pictures, which had been taken at speeds of from 750 to 2,000 frames per second were shown at the rate of about 10 frames per second. Those shown by Mr. Crawford depicted the phenomena occurring during the flash welding of 2 flat plates. Those shown by Mr. Winne depicted similar phenomena for various types of manually controlled arc welding with both alternating and direct current, and with both coated and bare electrodes. These pictures showed very clearly the short-circuiting of the arc by the globules of molten metal deposited from the electrode on the work. The showing of these pictures was followed by a period of informal discussion.

Registration for Inspection Trips

Trip	Registration
Cities Service broadcast	500
Hayden Planetarium	188
Radio City Music Hall	128
National Broadcasting Company studios	127
Bell Telephone Laboratories	115
S.S. "Monarch of Bermuda"	115
New York Stock Exchange (4 parties)	102
Columbia Presbyterian Medical Center	89
General Cable Corporation, Bayonne plant	76
Electrical Research Products, Inc.	71
East River generating station	41
RCA Manufacturing Company, Harrison, N. J.	40
General Electric House of Magic	38
N. Y. Police Department, ballistics and radio patron system	38
Metropolitan Device Corporation	35
Electric fireboat "John J. Harvey"—N. Y. Fire Department	25
Cable splicing school, N. Y. Edison Company	25
Fire fighting demonstration	(Cancelled)
Total	1,753

Attendance at Special Features of Recent Winter Conventions

Feature	1934	1935	1936
Total registration	1,227	1,114	1,231
Smoker	550	1,025	983
Dinner dance	464	442	486
Inspection trips	363	815	1,753

Lecture on Astronomy

Following the Edison Medal presentation ceremonies on Wednesday evening, January 29, Dr. Harlow Shapley, director of the Harvard College Observatory, delivered a lecture "Progress in Measurements of the Universe." He outlined the progress made in Harvard's 7 zone study of the universe, these zones being: the region of meteors, the solar neighborhood, the local star clouds, the Milky Way, the local group of galaxies, the inner metagalaxy, and the outer metagalaxy. This study is being carried out primarily at observatories in South Africa and in Oak Ridge, Mass. (near Concord). The lecture was illustrated profusely with slides made from photographs taken in the various Harvard observatories.

Inspection Trips

A total of 1,753 registered for inspection trips held during the convention, which is more than double the number registered last year. As in the past 2 years, the last day of the convention was reserved entirely for inspection trips, 7 of the 18 scheduled trips being held on that day. The fire-fighting demonstration which was scheduled to be held by the Pyrene Manufacturing Company at Newark, N. J., was canceled because of unfavorable ground conditions; otherwise all trips were held as scheduled.

Future AIEE Meetings

North Eastern District Meeting,
New Haven, Conn., May 6–8, 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

South West District Meeting,
Dallas, Texas, Oct. 26–28, 1936

Southern District Meeting,
Birmingham, Ala., Dec. 1936

Attendance at the various trips is shown in an accompanying tabulation. In charge of the committee responsible for this year's fine trips was S. A. Smith, Jr.; he was assisted by H. M. Chase, G. E. Dean, Henry Kurz, W. J. Quinn, H. O. Siegmund, H. B. Stoddard, E. R. Thomas, R. H. Twiss, and W. Y. Vedder.

Smoker

Always a popular feature of the winter convention, the smoker was none the less so this year. The affair was held at the Mecca Temple Casino, and 983 attended. Its popularity was attested by the fact that the facilities of the casino were taxed to the limit, all reservations having been sold well in advance of the opening day of the convention. An interesting program of entertainment featuring a variety of acts followed the dinner. George Sutherland was the chairman of the smoker committee; he was assisted by E. S. Banghart, K. F. Bellows, C. A. Butcher, G. D. Edwards, W. H. Farlinger, H. E. Farrer, W. H. Harden, L. F. Hickernell, W. Jordan, J. E. McCormack, T. V. Purrington, T. O. Rudd, H. C. Schlaikjer, D. W. Taylor, and E. F. Thrall.

Dinner-Dance-Buffet-Supper

The success of the combined dinner-dance and dance-buffet-supper during the past 2 years led to a continuation of the combined feature this year, which was held at the Hotel Plaza where the Grand Ballroom and adjacent facilities were reserved. A total of 486 members and guests attended, 198 attending the dinner-dance, 172 the dance-buffet-supper, and 116 both. Many of the participants commented on the excellency of the dinner and of the appointments. The committee in charge consisted of: C. S. Purnell, *chairman*, F. L. Aime, T. S. Bacon, L. W. Codding, L. P. Ferris, C. M. Gilt, J. E. Goodale, S. B. Graham, W. A. Kietzman, Thomas Maxwell, J. A. McHugh, and J. H. Pilkington.

Women's Entertainment

In addition to the social events and inspection trips on the regular convention program of interest to women, a program of special entertainment features was arranged for the women attendants at the convention. On Tuesday afternoon, January 28, a group of about 50 inspected the Florida Exhibit at Radio City, followed by dinner

and a trip through Radio City. In the evening, this group attended the radio broadcast of the "Jumbo" program at the Hippodrome Theater. On Wednesday, 51, exclusive of the committee, attended a luncheon bridge at the Engineering Woman's Club, and late in the afternoon went to the Hayden Planetarium on the regularly scheduled inspection trip to that point of interest. About 35 visited the Frick Art Gallery on Thursday. In addition to the foregoing, a number of the women attended some of the regularly scheduled inspection trips, notably those to the Radio City Music Hall, the S.S. "Monarch of Bermuda," and the New York Stock Exchange. The success of the women's program was attributed largely to the hardworking chairman of the women's entertainment committee, Mrs. A. F. Dixon; she was assisted by Mrs. J. W. Barker, Mrs. C. R. Beardsley, Mrs. H. P. Charlesworth, Mrs. H. C. Dean, Mrs. T. Fort, Jr., Mrs. A. H. Kehoe, Mrs. E. B. Meyer, Mrs. G. S. Rose, and Mrs. H. R. Woodrow.

Directors and Committees Meet

Following the usual custom, a meeting of the Institute's board of directors was held during the convention, as well as meetings of several of the technical committees. In addition, the annual meeting of the national nominating committee was held during convention week, in accordance with amendments to sections 30 to 34 of the Institute's Constitution approved at the 1935 summer convention. Reports of the meetings of the board of directions and of the national nominating committee are given elsewhere in this issue.

The technical committees that met during the convention are: relay subcommittee of committee on protective devices; A.S.A. standards subcommittee of sectional committee on transformers; technical program committee; committee on instruments and measurements; sectional committee on transformers; committee on power generation; sectional committee on mercury arc rectifiers; committee on communication; sectional committee on measuring instruments; subcommittee on conductors, towers, and wood poles; lightning arrester subcommittee of committee on protective devices; committee on safety codes; committee on protective devices; standards committee; and committee on research. At some of these meetings, round table discussions were held on various matters under the jurisdiction of the respective committees. In addition, special round table discussion sessions were held on the following subjects: network synthesis; sound; and transformers for communication purposes. A joint meeting of Student Branch Counselors and committees on Student Branches and education also was held.

Much credit is due the winter convention committee for the efficient manner in which arrangements for the various features were made and executed. This committee consisted of C. R. Beardsley, *chairman*, T. F. Barton, C. O. Bickelhaupt, A. F. Dixon, E. E. Dorting, C. R. Jones, W. R. Smith, George Sutherland, and R. H. Tapscott.

A.I.E.E. Directors Meet During Winter Convention

THE regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., Monday, January 27, 1936.

Present: *President*—E. B. Meyer, Newark, N. J. *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice Presidents*—C. V. Christie, Montreal, Canada; Mark Eldredge, Memphis, Tenn.; W. H. Harrison, Philadelphia, Pa.; N. B. Hinson, Los Angeles, Calif.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; R. H. Tapscott, New York, N. Y.; W. H. Timbie, Cambridge, Mass. *Directors*—F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; W. B. Kouwenhoven, Baltimore, Md.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; G. C. Shaad, Lawrence, Kans.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York. *National Secretary*—H. H. Henline, New York, N. Y.

The minutes of the board of directors' meeting held October 22, 1935, and of the executive committee meeting held December 11, 1935, were approved.

Reports were presented and approved of meetings of the board of examiners held December 18, 1935, and January 22, 1936. Upon the recommendation of the board of examiners, the following actions were taken: 1 applicant was transferred to the grade of Fellow; 18 applicants were elected and 21 were transferred to the grade of Member; 93 applicants were elected to the grade of Associate; 132 Students were enrolled.

The finance committee reported disbursements in January amounting to $17,768.87; report approved.

At its meeting held last October, the board of directors adopted the budget submitted by the finance committee with the understanding that the item of traveling expense allowances to certain Institute, District, Section, and Branch representatives would receive further consideration by the finance committee and the board of directors. The budget allowances for traveling expenses were at the rate of $7^1/_2$ cents per mile, one way, for all meetings except those connected with the winter convention in January and the summer convention in June, for which an allowance of 5 cents per mile was made. After reconsideration, the board voted to adopt the rate of $7^1/_2$ cents per mile, one way, for the present appropriation year.

Chairman Everett S. Lee of the membership committee reported that applications for membership received from May 1, 1935, to January 2, 1936, were $11^1/_2$ per cent in excess of the number received during the corresponding period of the previous year.

A resolution was adopted that the 1936 annual meeting of the Institute shall be held at Pasadena, Calif., Monday, June 22.

Cancellation of the proposed District meeting in Pittsburgh, Pa., in October 1936 was approved, and District meetings were authorized to be held in Dallas, Texas, October 26–28, 1936, and in Birmingham, Ala., in December 1936.

Upon the recommendation of the standards committee, the board approved a revision of A.I.E.E. Standard No. 26—Automatic Stations, which had been developed by the technical committee on automatic stations.

Upon invitation from the American Standards Association to nominate an individual to serve as a member of the board of directors of the A.S.A. for the year 1936, to fill a vacancy, Mr. H. P. Charlesworth was nominated to serve in this capacity. Messrs. R. E. Hellmund and H. E. Farrer were appointed additional alternates for Institute representatives on the electrical standards committee of the A.S.A.

The president was empowered to appoint the Institute's 2 representatives on the council of the American Association for the Advancement of Science for the year 1936, and later appointed Prof. V. Karapetoff and Dr. J. B. Whitehead.

Prof. W. I. Slichter was nominated for re-election as a representative of the Institute on the Engineering Foundation board for the 4 year term beginning in October 1936.

Mr. H. H. Barnes, Jr., was appointed an Institute representative on the Hoover Medal Board of Award for the unexpired term, ending in October 1941, of Dr. E. W. Rice, Jr., deceased.

An amendment to Section 91 of the bylaws was adopted, deleting the second paragraph of that section. This had contained an incomplete list of representatives of the Institute on various bodies, which list changes from time to time, and unnecessary specification of the terms of such representatives, which are fully specified in the bylaws or rules of the organizations concerned.

Chairman F. B. Jewett of the Committee on Iwadare Foundation reported receipt, from President T. Motono of the Institute of Electrical Engineers of Japan, of an expression of appreciation of the lectures delivered by Dr. Dugald C. Jackson in Japan last fall, and of the co-operation rendered by the committee of the A.I.E.E. in connection with the work of the Iwadare Foundation of the Japanese Institute.

Approval was given to the nominees recommended by the committee on engineering schools of the Engineers' Council for Professional Development for appointment as Institute representatives upon the delegatory committees in Regions III to VII inclusive in connection with the E.C.P.D. program for accrediting engineering schools.

An invitation to appoint a representative to attend the presentation ceremonies of the 1936 Washington Award to Dr. Charles F. Kettering, on February 26, was presented, and the president was empowered to appoint a representative. (President Meyer subsequently appointed Mr. L. A. Ferguson.)

Other matters were discussed, reference to which may be found in this or future issues of Electrical Engineering.

Edison Medal for 1935 Presented to Doctor Stillwell

THE Edison Medal for 1935, highest award of the A.I.E.E., was presented to Dr. Lewis B. Stillwell "for distinguished engineering achievement and his pioneer work in the generation, distribution, and utilization of electric energy," at a special session of the Institute's recent winter convention, Wednesday evening, January 29, 1936. Doctor Stillwell, who has been a consulting engineer for many years, has been a Fellow of the Institute since 1912; he has served the Institute as a member of many committees, and was a director 1896–99, vice president 1899–1901, and president 1909–10. He was awarded the Institute's Lamme Medal in 1933.

President Meyer presiding over the ceremonies

E. B. Meyer, president of the Institute, presided over the ceremonies. In opening the program, President Meyer said:

"It is seldom that such an array of brilliant men of our profession has congregated to honor a fellow member and, in this instance, one who played what we might term a fundamental part in the development of the electrical art.

"Man achieves; time records. Great years are but the reflection of the great deeds of great men. It is in the minds and souls of such men that the miracles have been wrought.

"We can find inspiration in looking back over the past years and in tracing the remarkable progress of the electrical industry. The colorful sequence of technological discoveries and developments, since the early days in the electrical field, stimulates the imagination, arouses enthusiasm, and revives the spirit, vision, and courage of its pioneers.

"Such men as Doctor Stillwell have served to vitalize our lives with the dynamic power of broader horizons, and have given us loftier ideals. To be associated with him in this great professional body is indeed a privilege and an honor."

President Meyer then introduced C. E. Stephens (M'22) chairman of the Edison Medal committee, who outlined the history of the medal and mentioned the previous recipients. Following Mr. Stephens' remarks, Dr. J. B. Whitehead (A'00, F'12, Life Member, and past-president) outlined the principal achievements of the medalist. His address follows.

Achievements of Medalist Outlined by Doctor Whitehead

"It is most appropriate that the award of the Edison Medal to Lewis Buckley Stillwell should fall in the year in which the Institute is celebrating the fiftieth anniversary of the establishment in this country of the alternating current system. In 1886 young Stillwell, 23 years old and just out of college joined the Westinghouse company, which was to play so large a part in the rapid development of that system and of which part Stillwell himself was to be so important a factor. At this time George Westinghouse had acquired the American rights to the Gaulard and Gibbs patents. Stanley had demonstrated both transformation and high voltage for transmission. Mr. Westinghouse was entering the electric field with Shallenberger as chief electrician, and Stillwell was employed as his assistant. The first commercial plant at Buffalo, N. Y., was just going into operation. The vision of long distance electric service was about to be realized. We can imagine the appeal made to young Stillwell's enthusiasm, and to the mind which so early gave evidence of wide vision and appreciation of the larger implications of engineering enterprise.

"Let Edward Dean Adams, President of the Cataract Construction Company, tell us of the romance in the appeal made by the prospect of Niagara power to those who had a vision of the possibilities of the alternating current system. In his Niagara Power he says:

"'Scientists had theoretically demonstrated . . . that the current could be controlled and distributed safely and economically . . . their laboratories were working out designs and engaged in the construction of experimental machines. The results were encouraging, but not commercial. Hope may have fathered the thought that the machines would be forthcoming; the stakes were high, the field was promising, and the community was expectant; success meant fortunes; there was an unmistakable demand that lured the inventor; the pioneer promoter had both courage and confidence. The necessity was recognized as the mother of the inventions required.'

"Into this romantic atmosphere came young Stillwell, and the rapidity with which he apparently absorbed available knowledge and built upon the contemporary sketchy theory of alternating currents, gives us a glimpse of the penetrating and restless mentality which is so evident throughout all his subsequent career. Such qualities apparently were appreciated immediately by Mr. Westinghouse, just then in process of assembling that brilliant group of electrical engineers who should match in the field of electricity his daring mechanical genius. It is reported that he gave instructions that when engineers were employed they should be 'gentlemen.' He was satisfied on all accounts with Stillwell, and the latter's rise in the Westinghouse company was rapid.

"In these early years his chief interest was in the laboratory, developing under Shallenberger methods for the control and the expansion of the new system. The Stillwell regulator was a product of this period, solving the problem of long line voltage regulation. In practically its original form the regulator survived through many useful years, and the principles then laid down are essential to the service of today.

"In 1889 the partisans of the direct and alternating current systems resorted to the public press and on one side even to litigation in their efforts to create public opinion for or against their favorite current. Stillwell, then 26 years old, was assigned by the Westinghouse company as technical adviser to counsel in the company's participation in the protest before a Senate committee of the State of Virginia, against a bill there introduced which would have restricted the value of voltage of the alternating current system as compared with the direct current system. Mr. Edison appeared on the other side.

"In 1890 Stillwell was sent to Europe to study the development of electric power and alternating current practice in various centers on the Continent. At that time President Adams and other representatives of the Niagara power project were in London consulting European scientists and manufacturers and organizing the International Niagara Commission. They had invited competitive general engineering plans. Stillwell and Reginald Belfield, electrician of the new British Westinghouse company, conferred with President Adams and Chief Engineer Coleman Sellers of the Niagara company. Stillwell wished to enter the competition with the Westinghouse alternating current system. Mr. Westinghouse demurred, his pungent comment afterward

Membership—

Mr. Institute Member:

This is the season when we are inviting Enrolled Students into Associate membership in the Institute. There are some 1,300 Students who are eligible to join the Institute at this time without the payment of entrance fee. These Students are being invited by letters and by personal visits from the members of the Section membership committees.

As you may have opportunity to know these Students you will be glad to invite them into Institute membership at this time.

Everett S. Lee

Chairman National Membership Committee

being: 'These people are trying to get $100,000 worth of information for a prize of $3,000. When they are ready to do business, we will submit a plan and bid for the work.' That his confidence was not misplaced is well known, for in 1893 the historic contract for the first generators and electrical equipment for the Niagara Falls Power Company was awarded to the Westinghouse company with its 2 phase alternating current system.

"At this time Stillwell was 30 years old and the Niagara enterprise was to give him his first great opportunity. The youthfulness of the group of engineers to whom its execution was entrusted is noticeable as is the ultimate distinction of each of them: Shallenberger (too soon to be cut down by death), Stillwell, Schmid, Lamme, Scott, Skinner, Davis, Wurts, and others. Stillwell's part was conspicuous and his influence and leadership are evident throughout the planning and execution of an enterprise which not only was record breaking and revolutionary in many of its aspects, but which immediately attained a success that in later years, was described by Mr. Adams as follows:

" 'The choice of polyphase alternating current has stood the test of time. . . . The Niagara Power system 30 years ago without precedent, now appears as a miniature of the electric power service which is making electricity the greatest tool that ever came under the control of man. . . . Furthermore no method is known by which power transmission and distribution on the scale it is conducted today, could be carried on, other than that which was initially selected at Niagara.'

"C. F. Scott, one of Stillwell's earliest associates and friends, says of him at this time:

" 'He looked at things in their larger relations, in perspective; he was general engineer; the plans for large stations, the plans for the polyphase exhibit at the World's Fair, Chicago, 1893, the selection of 60 cycles as a standard frequency, the negotiations with the Niagara Falls Power Company . . . were all matters in which he had a leading part.'

"His position, therefore, as general engineer in the Westinghouse-Niagara project is accounted for by his wide vision, his keen engineering insight, his quiet dignity in every situation, and perhaps best of all by his own modest description of the part he played in these great enterprises. In referring to the history of the development and construction of the Niagara equipment, he said: 'We all worked together with enthusiasm and harmony.' To those of us who were fortunate enough to enter the Westinghouse atmosphere at that time, the spirit of enthusiasm and harmony was abundantly evident and a never-to-be-forgotten inspiration.

C. E. Stephens outlines history of Medal

"In 1895 Stillwell had the satisfaction of seeing the completion of the first Westinghouse contract and the full fruition of his participation in his first great enterprise in its completely satisfactory operation.

"As engineer of the Westinghouse company, he continued his supervision of the electrical work at Niagara; and in March 1897, severing his connection with Westinghouse, he became electrical director of the power company. In 1899, with the consent of the power company, he was appointed consulting electrical engineer of the Manhattan Railway Company of New York, dividing his time between Niagara and New York.

"In September 1900, he resigned his position with the power company, established an office in New York, and entered upon his long and useful career as consulting engineer. Beginning in a time in which many were attracted to this field by the clamoring opportunities in the rapid expansion of electric power, he has been conspicuously successful through the succeeding years. His professional equipment, extending beyond technical knowledge, skill, and their applications, embraced always a far vision of specific as well as general economics, particularly if, as was often true, his problem involved the welfare and convenience of large groups of the public. He was fitted for the large and varied problem and many such came to him.

"It is not my purpose to survey the long list of important projects which owe their success to Doctor Stillwell's care and skill. This record already is written in many places. Suffice it to say that many of them have involved wide departures and advances over existing experience, as well as the uncertain elements always present in estimates of future channels of movement and directions of growth. Among his greatest engagements were several in the field of rapid transit and the applications of electric power thereto. The problems in this field entrusted to him, and his public utterances thereon, indicate the depth of his study, his vision of future development, and his balanced judgment in plan and execution. Perhaps his taste and abilities in this special field were due to his intensive study of the ever present problems of rapid transit within New York City. Second perhaps only to the Niagara project in the length of the steps beyond existing practice, and in the variety and magnitude of new elements, was that of the plans and electrical equipment for the first rapid transit subway in New York City, his identification with this project extending from 1900 to 1909. Other important work of similar character include the electrical equipment of the Manhattan Elevated Railway, that of the Hudson and Manhattan Railroad, reorganization and extension of the power supply system of the United Railways and Electric Company of Baltimore; many consulting relationships as, for example, those of the Wilkes-Barre and Hazleton (Pa.) Railway, the first electric railway in America to use a plank guard horizontally suspended above the third rail; electrification of the Hoosac Tunnel on the Boston and Maine Railroad in the northwestern part of Massachusetts; the Interborough Rapid Transit Company; and many others. In another direction, and also interesting in its departure from conventional methods, were his services to the Lehigh Coal and Navigation Company which resulted in the first large power installation in America at the 'mouth of the mine,' and the attendant electrical distributing system. We need not proceed further with the list, particularly as further survey has been given by Past-President D. C. Jackson in his fine citation on the occasion of the award of the Lamme Medal to Doctor Stillwell at the A.I.E.E. 1934 summer convention.

"Rather in the few minutes at my disposal, I would bring to your attention some of the evidence of Doctor Stillwell's deep sense of the opportunities for public service open to the engineer, and the consequent responsibility upon him to give of his best and always in accordance with the highest ethical and professional principles. Despite the exacting requirements of the planning and execution of such important projects as those we have mentioned, and in spite of health not always too robust, he has found time to give to the profession and to the public many results of his careful study and analysis, to take active part in movements looking to a more unified position and activity of the engineering profession in public affairs, and to reveal constantly his conception of the higher principles of conduct and professional relations which the engineering profession should set for itself. No better evidence of the spirit that guides the man can be found than in the fact that in spite of a scarcity of vocal or written pronouncements specifically setting forth his ideals, Doctor Stillwell long has been regarded by his fellow engineers as a leading exponent in all movements calling for disinterested public service and a high code of professional conduct.

Doctor Whitehead sketches high lights of Stillwell career

"Motives and action of this character clearly are indicated in several of his papers published in the A.I.E.E. TRANSACTIONS. 'The Electric Transmission of Power from Niagara Falls,' published in 1901 (volume 18, pages 445–531) is a splendid example of a gift to his profession of the technical methods of solution of a major problem. 'On the Substitution of the Electric Motor for the Steam Locomotive,' published with Henry St. Clair Putnam in 1907 (volume 26, 1907, pages 31–101) is a remarkable example of the balancing of the powers of a new agent still untried, against the requirements of the greatest of all problems of transportation. Here was a great service to capital, to the profession, and to the public, well rounded in its discussion of both professional technique and public economy. Its value and importance may be appreciated in the fact that in every major particular the promises of this brilliant analysis have been realized. In the 2 papers 'Electricity and the Conservation of Energy,' published in 1909 (volume 28, pages 163–78) and the 'Conservation of Water Powers,' his Presidential address to the Institute in 1910 (volume 29, pages 1037–52) Dr. Stillwell went still further, extending his fine powers of analysis to the then important public question of the relations of hydroelectric power to the con-

servation of the nation's resources. No better example could be found of the type of service which a competent engineer with a high sense of public duty may render to a government sincerely in search of guidance.

"His constant interest and effort for the engineering profession are also exemplified in many other activites within the Institute. In 1910 he was chairman of a committee on conservation of natural resources, demonstrating the methods in which the Institute might participate in many similar public questions to follow. Later, through 4 years, he served on the committee on public policy. It was during this time that his address, 'The Status of the Engineer' at a symposium on this subject (A.I.E.E. TRANSACTIONS, volume 34, 1915, pages 293–301) marked the beginning of the long continued effort to bring together in some co-ordinate form the common interests of the various branches of the profession, and which culminated in the establishment of American Engineering Council. Beginning in 1921, he was for 2 years the Institute's representative on American Engineering Council. In succeeding years he constantly supported Council in various ways and subsequently served for 4 years, from 1930 to 1934, as its vice president, thus indicating his constant interest in the public duty and public status of the engineer. His frequent contributions to discussions in Council were, as in all his public utterances, marked by careful inquiry, balanced judgment, and sound conclusion, presented with dignity invariably carrying conviction and respect. On one occasion, he was moved to indignation. Council had offered its services to one of the large governmental agencies of the present administration entrusted with undertakings requiring the employment of engineers. A rebuff indicating indifference and in terms of discourtesy had been received. In the Assembly of Council, Doctor Stillwell in no uncertain terms voiced his opinion of such treatment and his conception of the high type and value of services available in the engineering profession to a conscientious government agency, and moved a rejoinder addressed to a higher authority, quietly but firmly putting the matter in its true light.

"Naturally Doctor Stillwell's affiliations with scientific and engineering societies have been extensive. He is a member of the National Academy of Sciences, of the American Philosophical Society, of the Franklin Institute, of the British Institution of Electrical Engineers, of the American Society of Civil Engineers; he is a Fellow of the Royal Society of Arts of Great Britain; he is a past-president of the American Society of Consulting Engineers, and of the American Institute of Electrical Engineers.

"Honors conferred upon him have been numerous. He received the honorary degree of master of science from Lehigh University in 1907, of doctor of science from Wesleyan University in 1907, and of doctor of science from Lehigh University in 1914. In 1899 he was awarded the Niagara Medal by the president of the Niagara Falls Power Company. In 1929 the American Society of Civil Engineers conferred upon him a medal 'for leadership as chairman of Engineering Foundation, in consolidating the research work of the Foundation and the Founder Societies.' In 1933 he was awarded the Lamme Gold Medal by the American Institute of Electrical Engineers for his 'distinguished career in connection with the design, construction, and operation of electrical machinery and equipment.' He was a member of National Research Council during the World War, chairman of Engineering Foundation 1924–28, director of the Chamber of Commerce of the United States 1921–23. He is a member of the Holland Society of New York and he has been a life trustee of Princeton University since 1920.

"The American Institute of Electrical Engineers now signalizes the distinction of his career by its highest award, the Edison Medal."

Doctor Stillwell Speaks on Professional Ethics

At the conclusion of Doctor Whitehead's address President Meyer presented the medal and engraved certificate to Doctor Stillwell who responded as follows:

"I appreciate keenly the high honor of the award of the Edison Medal for 1935.

"Some 25 years ago, while president of the Institute, I had the honor of handing the first Edison Medal to that dean of our profession, Dr. Elihu Thompson, and on that occasion ventured the following prophecy:

" 'The Edison Medal, awarded from year to year by the deliberate judgment of a jury competent, conservative, and judicial, is destined to become the most distinguished symbol of success in the field of electrical science. Established as a memorial to a man who, himself standing at the summit of achievement as an inventor, realizes as Newton did the infinite possibilities beyond the boundaries of present knowledge, its award by the American Institute of Electrical Engineers is an honor which may well constitute through the years to come an incentive to ambition and stimulus to earnest endeavor.'

"Since that evening in 1910 when Doctor Thompson became the first Edison Medalist, my sense of the honor implied by its award has steadily grown, as one distinguished name after another has been added to the roll of its recipients. It is, therefore, with augmented realization of the significance of this award that I thank you for the honor you have done me.

"My good friend, Doctor Whitehead, has left me little excuse for reminiscence. That he is a researcher of the first class I have long known. That he has a strong archæological tendency is evident from his success in digging up items relating to the early days of alternating current now generally forgotten. In his investigation of my record, he has examined it through the eyes of a friendship which I long have prized, and for which I am grateful.

"No candid man can review his record and fail to recognize how much he has owed to opportunity—often to circumstances over which he had little or no control. And still further, if his work has been done in close association with fellow workers, and especially if during his professional career he has been loyally assisted by expert associates, he must recognize how much of the credit which comes to him belongs, at least in part, to them.

"In the early days at Pittsburgh it was my good fortune to be associated with a remarkable group of able young men who worked together with perfect co-operation and harmony. The leadership of George Westinghouse and the stimulus of his example were inspiring. The friendships then formed have persisted among the survivors of that group to this day.

"At Niagara, I was ably assisted by Paul Lincoln and Philip Barton; and after my offices were established in New York, the ability and untiring work through many years of John van Vleck, H. St. Clair Putnam, Hugh Hazelton, M. G. Starrett, and others earned much of the honor which has come to me tonight.

"Charles F. Scott, in his response on receiving the Edison Medal, January 29, 1930, described the evolution of electric power, and called attention to the fact that this evolution comprised 3 great steps, namely, the direct current Pearl Street station in 1882, the single-phase alternating-current service in 1886, and the polyphase alternating current system on an outstanding scale at the Niagara plant in 1895.

"The first of these steps was taken by Edison. Not only did he produce the incandescent lamp, but he designed and built the dynamos and a complete system of electric distribution which from the outstart was a commercial success. The feeder and main and the 3 wire system were his inventions and of this period. The limitation of the system was its comparatively low voltage, which practically restricted distribution to a radius not greatly exceeding 1/2 mile from the central station.

Doctor Stillwell responds

"The second step involved the development and introduction of the modern transformer and the use of alternating current. Credit for this step is due chiefly to George Westinghouse, inventor of the air brake, and to William Stanley, O. B. Shallenberger, Reginald Belfield, and others, who early became associated with him as electrical experts. Few if any of that early group contributed more than that master of mechanical design, Albert Schmid.

"The development and commercial introduction of the new system was rapid. Within 3 years of the installation at Buffalo, N. Y., of the first commercial alternating current plant in America, more than 200 central stations using single phase alternating current were in operation. While Westinghouse was the recognized leader in this development, the Thompson-Houston Company at an early date became active in this field. Roughly speaking, the development and commercial introduction of the single phase system covered the period from the latter part of 1885 to the inauguration of commercial service at Niagara and Buffalo in 1895. The transformer was the key to the solution of the problem of transmitting electricity over long distances; but several years of effort failed to produce a satisfactory alternating current motor for that system.

"On May 1, 1888, United States patents covering the induction motor and polyphase

systems were taken out by Nikola Tesla. Westinghouse promptly acquired the American rights, and from that time until the autumn of 1892, development of the polyphase system was carried on at Pittsburgh.

"Progress at first was slow. Primary attention of the designing staff was devoted to improving single phase apparatus and to direct-current street-railway equipment. For a year or 2, beginning in 1890, development work was retarded by financial difficulties of the company. Meantime, however, progress was made with the Tesla motor and the advantages of a lower frequency than that used in the single phase system were studied. Before the end of 1890 the Company's engineers decided definitely that the advantages of polyphase current were controlling, and they selected a frequency of 60 cycles for general use and an alternative of 30 cycles for plants in which a large part of the power was to be used in the form of direct current.

"Within a year or 2 excellent polyphase motors were produced. At the Frankfort Exposition of 1891, a German company exhibited successful rotary converters. In the following year machines of this type giving excellent results were built and tested at Pittsburgh, and the polyphase system in its essentials was complete.

"Westinghouse having secured the contract for lighting the World's Fair, half a dozen 750-kw 2-phase 60-cycle alternators were built and installed for that purpose. Coincidently, an extensive exhibit of the system operating at 30 cycles was constructed and sent to Chicago. It was a complete demonstration of the polyphase system. Its performance was highly satisfactory, as also was that of the 60 cycle alternators.

"Immediately following the successful tests of rotary converters at Pittsburgh in the autumn of 1892, the Cataract Construction Company, of which Edward D. Adams was then president, was notified by Westinghouse that he now was ready to submit tenders for a complete electric system to generate, transmit, and utilize Niagara power, and at points of consumption to deliver either alternating or direct current as might be required. In October 1893 the contract for the initial plant at Niagara, comprising 3 2 phase alternators, each capable of deliverying 5,000 electric horsepower was closed, and 2 years later the plant was in successful commercial operation. The problem of transmitting and distributing electricity over distances limited only by ability to insulate transformers and transmitting conductors had been solved. That solution has stood the test of time.

"Until 1892 the Westinghouse company met no serious competition in the polyphase field. In that year, however, the Edison and Thompson-Houston companies were combined, forming the General Electric Company. This company and the Westinghouse company pooled their patents, thus providing an unobstructed field for their inventors and designers. From that time competition was keen. Steinmetz, Emmet, and their assistants at Schenectady, counseled by Thompson and Rice, were worthy rivals of Schmid, Lamme, and Scott at Pittsburgh. The stimulus of competitive effort was an important factor in advancing polyphase practice to the high plane of technical excellence it holds today.

"Upon an occasion like this the temptation to indulge in reminiscence is strong. But I must not impose further upon your good nature by retelling a story which many of you have heard from others; and I hope it will not be considered out of order to turn to a subject which, as I see it, deeply concerns the future of the engineering profession.

"Dr. Whitehead has alluded to the importance of strict observance by the engineer of high ethical principles in the practice of his profession. This, of course, applies especially to the engineer who professionally advises a client. Any failure on his part to observe such principles tends to lower the reputation of the entire profession in the eyes of the public. This is a matter of importance not only to the consulting engineer, but to all engineers however employed.

"Instead, therefore, of trespassing further upon your patience by repeating the story of technical progress in electrical engineering, which has been covered by others, I venture to devote the remainder of my time this evening to the professional ethics of the engineer. Time permits only a brief glance.

"According to the census of 1930, the number of technical engineers in the United States in round numbers was 226,000. The number of individual engineers holding membership in engineering and allied technical societies, as of 1929, was 115,000. Even in that time of extreme industrial and commercial activity, less than half the men classified by the census as engineers were members of any engineering society. More than half in no way were bound by an obligation to observe any code of professional ethics established by an engineering society. Further, there is but too much reason to believe that some engineers who are members of one or more engineering societies pay little attention to codes or to the principles upon which they are based.

"For the vast majority of professional engineers one must have great respect. Almost invariably I have found them men of high character and scrupulous integrity. Their training in science and engineering has taught them respect for truth and aversion to devious thinking; and this, in the aggregate, should, and I believe does, make them a strong moral force in the community. By so much the more is it important that the engineer, and particularly the consulting engineer, who violates ethical principles in his practice be eliminated, if that be possible.

"A large proportion of the members of our profession are employees and are not directly responsible for the ethics of their employers; but in the country at large there are many engineers individually employed by states, municipalities, banks, railroads, and industrial corporations to give professional advice and guidance, presumed to be as purely professional as that which a client receives from a lawyer of the highest character and standing. Obviously, it is of profound concern to our profession that no engineer so employed should be serving 2 masters. The engineer who pretends to give unbiased advice to his client while receiving or expecting to receive any emolument other than his agreed salary or fee from that client (except as may be agreed upon with the client in writing) is an enemy of the profession.

"What is our profession doing to correct abuses of this kind? Our great national engineering societies have adopted codes of practice, and from time to time have endeavored to enforce them in cases where their provisions have been violated. But enforcement is difficult, and efforts to enforce have been, for the most part, sporadic.

"The American Institute of Consulting Engineers, founded in 1910 as successor to an association of engineers organized May 2, 1905, has devoted much time and effort to advancing the status of the engineer by establishing and strictly observing the provisions of its code of professional practice, and in other ways. Included in its membership, numbering slightly more than 100, are many of the recognized leaders of the profession. Of these, half have their offices in New York, and the others are scattered widely over the country.

"With headquarters in San Francisco, the Pacific Association of Consulting Engineers, a small group of the leading engineers of that section, has made similar efforts for many years.

"The St. Louis Institute of Consulting Engineers, comprising some 20 or 25 members, using a code practically identical with that of the American Institute of Consulting Engineers, has been active since 1924 with good results.

"The question is: What can be done to correct the evils of the present situation? I have found no complete and satisfactory answer. It seems clear, however, that the problem is of such far reaching importance, both to the profession and to the public, as to call for a prompt, well-planned, and persistent effort to correct abuses which are widely recognized. If I may presume to

Some prominent Institute members at the Edison Medal presentation ceremonies; left to right Past-President H. P. Charlesworth, Vice President F. O. McMillan (District 9), Director G. A. Kositzky, National Treasurer W. I. Slichter, Director F. M. Farmer, C. R. Beardsley, chairman, 1936 winter convention committee, Director G. C. Shaad, Vice President W. H. Timbie (District 1), W. R. Smith, chairman, technical program committee, and Vice President Mark Eldredge (District 4)

offer a suggestion, the first step would be the appointment by the 4 great national engineering societies, usually designated the Founder Societies, of a strong and energetic committee to study the problem and propose a plan of united action by the societies. It is an ideal opportunity for close co-operation.

"In recent years, many states have enacted laws requiring practicing professional engineers to be licensed by the state. While this complicates the problem, it seems possible that it may become a very important factor in its ultimate solution.

"An experience of the American Institute of Consulting Engineers may be useful. Some years ago, that institute endeavored to promote the organization of an active local society like that in St. Louis in each of the chief centers of engineering activities. The attempt failed. In one large city, for example, it appeared that while the need of such a society was recognized, there was not a sufficient number of recognized consulting engineers in the region centering in that city to form an effective group for the purpose contemplated. Is it not possible that this experience suggests an answer to the problem? Would it not be possible for the Founder Societies to organize in Chicago, for example, an active joint committee on professional ethics? The members of such a committee would be selected, naturally, from engineers of high character and, preferably, from those in independent practice. Self-interest, as well as a desire to improve the standing of the profession, it would seem might be relied upon to insure vigilance and activity. A central committee in New York or Washington could assist the local or regional committee, could keep in touch with it, and from time to time, report results to the Founder Societies. Existing societies of consulting engineers doubtless would co-operate, and their experience would suggest methods of promoting attainment of the common objective.

"In recent years, teachers of engineering in our colleges frequently have been employed to give expert advice. These men, in general, have high standing in their respective communities, and many of them might be glad to serve as members of a regional committee.

"But I must close. I thank you for your patience in listening and for the reception you have given me this evening."

Summer Convention Plans Progressing

Plans for the A.I.E.E. summer convention, which will be held at the Huntington Hotel, Pasadena, Calif., June 22–26, 1936, will develop into a program of many attractive features. The technical sessions will be devoted particularly to the needs of western engineers, and the papers will combine the latest experiences and engineering developments obtained from both the East and the West. Pasadena provides a beautiful setting and the trip through the Rocky Mountains from points east affords an abundance of scenery. There will also be ample opportunity for sports, entertainment, trips and recreation.

Tentative arrangements call for 8 technical sessions, with possibilities of 2 or 3 others developing. Several of the papers will be by well-known Pacific Coast engineers. The scope of the program so far planned deals with the subjects of education, illumination, electrophysics, conductor vibration, protective devices, rotating electrical machinery, transformers, and a group of selected subjects. Engineering education will be presented from a broad general point of view as a preparation for life. Another paper will outline the position of the young engineer in industry under changing conditions, and a third will look toward the future from an educational viewpoint. In the session on conductor vibration 2 papers will present the latest work done at Stanford University (Calif.) on energy relations of vibration and the wind tunnel. High voltage circuit breakers and special tests, as well as relaying, will form the principal basis for discussion at the session on protective devices. Induction motor load loss tests and applications, and hydrogen cooling, will comprise a good part of the session on electrical machinery. Other topics will be announced in subsequent issues of Electrical Engineering.

The names of members of the committee making arrangements for the convention were announced in the February issue, page 210.

Special Train Contemplated

Those interested in combining a vacation trip with attendance at the summer convention, may be interested to know that a special train may be arranged to transport members from the East to and from the convention, at special rates. According to tentative plans there will be an opportunity to visit Boulder Dam and other power developments along the route. It will be of considerable help to the committee formulating plans for this special transportation facility if those interested will communicate their interest to national headquarters of the A.I.E.E., 33 West 39th Street, New York, N. Y.

North Eastern District to Meet in New Haven May 6-8

New Haven, Conn., the home of Yale University, will be host to a 3 day meeting and Student Branch convention of the A.I.E.E. North Eastern District, May 6–8. Tentative plans call for 5 technical sessions, one of which will be devoted exclusively to papers by students. Interesting inspection trips to industries in the vicinity of New Haven will be arranged, and a dinner and entertainment will be held on Thursday evening.

Present plans call for technical sessions Wednesday, May 6, both in the morning and afternoon, Thursday, May 7, in the morning, and Friday, May 8, both in the morning and afternoon. Friday morning's session will be devoted to the presentation of papers by Enrolled Students; since this will be the only Student session, the papers will be limited to one from each Branch. Some subject matter under consideration for the technical sessions will have a broad general appeal, while other material will be

Candid Camera Studies

of some of those who attended the Institute's 1936 winter convention at New York in January

Top row shows several attendants at the dinner-dance: (1) Mrs. A. M. Dixon, chairman, women's entertainment committee; (2) C. R. Beardsley, chairman, winter convention committee; (3) D. M. Simmons, former chairman of the Institute's power transmission and distribution committee, conversing with Mrs. L. G. Smith of Baltimore, Md.; (4) Mark Eldredge, vice president, A.I.E.E. Southern District; (5) Ernst Weber, member of the Institute's committee on research; (6) W. R. Smith, chairman of the Institute's technical program committee; (7) F. O. McMillan, vice president, A.I.E.E. North West District; and (8) George Sutherland, chairman, smoker committee

(9) Past-Presidents Chas. F. Scott and A. W. Berresford discussing the forthcoming celebration of the fiftieth anniversary of the establishment of the alternating current system in America

(10) A. H. Kehoe, member of the Institute's standards committee, at the right; Past-Director H. R. Woodrow may be seen on the left, at the far side of the table

(11) L. F. Hickernell (left), member of the Institute's committee on power transmission and distribution, conversing with S. Murray Jones, former member of the Institute's committee on protective devices, at the smoker

(12) Frank M. Starr (front), recipient of the 1932 Alfred Noble prize, at the dinner-dance; at the left is R. H. Park, former member of the Institute's committee on electrical machinery

(13) F. H. Hollister, chairman of the Institute's power generation committee, at the dinner-dance

(14) The receiving line at the dinner-dance (right to left): President E. B. Meyer, Mrs. Meyer, National Secretary H. H. Henline, Mrs. Henline, C. R. Beardsley, chairman, winter convention committee, and Mrs. Beardsley

(15) W. H. Harrison, vice president, A.I.E.E. Middle Eastern District, with water glass raised; C. O. Bickelhaupt, chairman of the Institute's publication committee, is an interested observer (left edge of picture)

(16) Past-President P. M. Lincoln at the smoker

(17) H. E. Farrer, secretary of the Institute's board of examiners and standards committee, and a member of headquarters staff, at the dinner-dance

(18) A. M. MacCutcheon (left), nominee for president, interests P. L. Alger (center) former chairman of the Institute's committee on electrical machinery, and National Treasurer W. I. Slichter (right)

(19) Frank Thornton, Jr., member of the Institute's committee on safety codes, at the dinner-dance

(20) N. B. Hinson, vice president, A.I.E.E. Pacific District

(21) Director L. W. W. Morrow and Past-Director A. E. Knowlton at the inspection trips desk

(22) The registration desk


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more specialized but selected because of its particular interest to the membership in the locality.

Inspections are planned as follows:

Wednesday Evening, May 6. Inspection of 3 of the new Yale University buildings—the library, the graduate school, and the gymnasium—with an alternate trip through the dial station plant of the Southern New England Telephone Company.

Thursday Afternoon, May 7. Inspection of locomotive and passenger equipment of the New York, New Haven, and Hartford Railroad followed by trip to the Wallingford Steel Company, with alternate provision, especially for the ladies, to visit the silverware manufacturing plant of R. Wallace and Sons Manufacturing Company. Both these plants are in Wallingford.

Saturday Morning, May 9. Trip to the Sikorsky Aircraft Company plant in Stratford.

Arrangements will be made for small groups to visit the various manufacturing plants in and around New Haven at convenient times.

It is hoped that the students will arrive Thursday and take both inspection trips. The trip on Saturday to the Sikorsky Aircraft Company, where the large clipper ships are made, should prove to be of unusual interest.

Reasonable lodging will be provided for students in local hotels at $1.00 per night. The program and other details will be announced in the April issue of Electrical Engineering.

Nominating Committee Announces Candidates

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1936, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, N. Y., January 29, 1936. This committee, in accordance with the constituion and by-laws, consists of 15 members, one selected by the executive committee of each of the 10 Geographical Districts, and 5 selected by the board of directors from its own membership.

The following members of the committee were present: C. V. Christie, Montreal, Canada; F. M. Craft, Atlanta, Ga.; H. S. Evans, Boulder, Colo.; F. M. Farmer, New York, N. Y.; W. H. Harrison, Philadelphia, Pa.; O. W. Holden, Los Angeles, Calif.; W. B. Kouwenhoven, Baltimore, Md.; F. H. Lane, Chicago, Ill.; Everett S. Lee, Schenectady, N. Y.; F. O. McMillan, Corvallis, Ore. (alternate for J. A. Thaler); C. W. Mier, Oklahoma City, Okla.; A. C. Stevens, Schenectady, N. Y.; W. H. Timbie, Cambridge, Mass.; W. E. Wickenden, Cleveland, Ohio; H. R. Woodrow, Brooklyn, N. Y.

The following is a list of the official candidates selected by the committee:

For President

A. M. MacCutcheon, engineering vice president, Reliance Electric and Engineering Company, Cleveland, Ohio.

For Vice Presidents

A. C. Stevens (North Eastern District, number 1) in charge of educational sales, General Electric Company, Schenectady, N. Y.

O. B. Blackwell (New York City District, number 3) manager of staff departments, Bell Telephone Laboratories, Inc., New York, N. Y.

C. Francis Harding (Great Lakes District, number 5) head, school of engineering, and director of the electrical engineering laboratories, Purdue University, West Lafayette, Ind.

L. T. Blaisdell (South West District, number 7) southwestern district manager, General Electric Company, Dallas, Texas.

C. E. Rogers (North West District, number 9) chief engineer, Pacific Telephone and Telegraph Company, Washington-Idaho Area, Seattle, Wash.

For Directors

K. B. McEachron, research engineer in charge of high voltage practice, General Electric Company, Pittsfield, Mass.

C. A. Powel, manager, central station engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

R. W. Sorensen, professor of electrical engineering, California Institute of Technology, Pasadena, Calif.

For National Treasurer

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The constitution and by-laws of the Institute provide that the nominations made by the national nominating committee shall be published in the March issue of Electrical Engineering. Provision is made for independent nominations as indicated in the following excerpts from the constitution and by-laws:

Constitution

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice presidents shall be signed only by members within the District concerned.

By-Laws

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (constitution), must be received by the secretary of the national nominating committee not later than March twenty-fifth of each year, to be placed before that committee for inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the National Nominating Committee in accordance with article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(Signed) National Nominating Committee
by H. H. Henline, *Secretary*

Biographies of Nominees

In order that those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been nominated, brief biographical sketches are given on pages 311–13 of this issue.

Lamme Medal Awarded to Vannevar Bush

"For his development of methods and devices for application of mathematical analysis to problems of electrical engineering," the 1935 A.I.E.E. Lamme Medal has been awarded to Dr. Vannevar Bush (A'15, F'24) vice president and dean of the school of engineering, Massachusetts Institute of Technology, Cambridge. The medal will be presented to him at the summer convention of the Institute, Pasadena, Calif., June 22–26, 1936. A biographical sketch of Dr. Bush may be found on page 313 of this issue.

The Lamme Medal was founded as the result of a bequest of the late Benjamin G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, who died on July 8, 1934; this bequest provides for the award by the Institute of a gold medal (together with a bronze replica thereof) and a certificate annually to a member of the A.I.E.E. "who has shown meritorious achievement in the development of electrical apparatus or machinery," and for the award of 2 such medals in some years if the accumulation from the funds warrants. A committee composed of 9 members of the Institute awards the medal; A. M. MacCutcheon (A'12, F'26, and nominee for president) is chairman of the committee that awarded the 1935 medal to Doctor Bush. Previous recipients of the award have been: 1928, A. B. Field (A'03, F'13); 1929, R. E. Hellmund (A'05, F'13); 1930, W. J. Foster (A'07, F'16); 1931, Guiseppe Faccioli (A'04, F'12); 1932, Edward Weston (A'84, M'84, member for life and past-president); 1933, L. B. Stillwell (A'93, M'92, F'12, member for life and past-president); and 1934, H. E. Warren (A'02).

British Institution Offers Courtesies to A.I.E.E.

A recent communication received at Institute headquarters, from the Institution of Civil Engineers, London, Eng., states that as a matter of courtesy, suitably introduced members of the A.I.E.E. visiting England will be accorded the privileges of attending the meetings of the Institution and of using the Institution's library and reading rooms. Further, such accredited visitors will be presented with letters of introduction to members of the Institution, if they so desire, to enable them to visit engineering works in England.

The A.I.E.E., of course, will be pleased to extend similar courtesies and privileges to members of the Institution who may visit the United States.

Eta Kappa Nu to Recognize Young Engineers

Eta Kappa Nu, honorary electrical engineering society, has announced a plan of recognizing outstanding young electrical engineers for "meritorious service in the interests of their fellow men." The achievements that will be considered in making selections are very broad, giving considerable weight to the recommendations of the committee on professional training of the Engineers' Council for Professional Development. Each candidate's career will be studied under 3 headings:

1. Achievements in his chosen professional work.
2. What he has done for his community, state, or nation.
3. How he has demonstrated his cultural development.

As far as practicable the young engineer's accomplishments of whatever kind will be examined for an application of basic engineering methods.

Each Section of the A.I.E.E. is invited to make nominations. Nominees must have been graduated from a regular 4 year course in electrical engineering not more than 10 years on April 1, nor be more than 35 years of age. Nominations should be sent to A. B. Zerby, national secretary of Eta Kappa Nu, Penn-Lincoln Hotel, Wilkinsburg, Pa., by April 1. The men selected in 1936 will head what is contemplated will become a coveted list of outstanding young American electrical engineers.

This plan of recognition has been worked out by the award organization committee of Eta Kappa Nu, of which Roger Wilkinson is chairman; other members of the committee are O. W. Eshbach (A'17, M'30), Clifford Faust (A'35), H. H. Henline (A'19, M'26, and national secretary), and E. S. Lee (A'20, F'30).

Explanation of January 15 Disturbance on New York Edison System

BECAUSE of the widespread interest aroused by the disturbance occurring on the New York (N. Y.) Edison system on January 15, 1936, which darkened a portion of uptown Manhattan, stalled subway trains, and caused other inconveniences, President E. B. Meyer instigated negotiations resulting in the appearance of H. C. Forbes (A'25, M'30) system engineer of the Edison company, at a special session of the Institute's recent winter convention on Wednesday morning, January 29, who gave a brief report on the disturbance. Mr. Forbes's remarks follow:

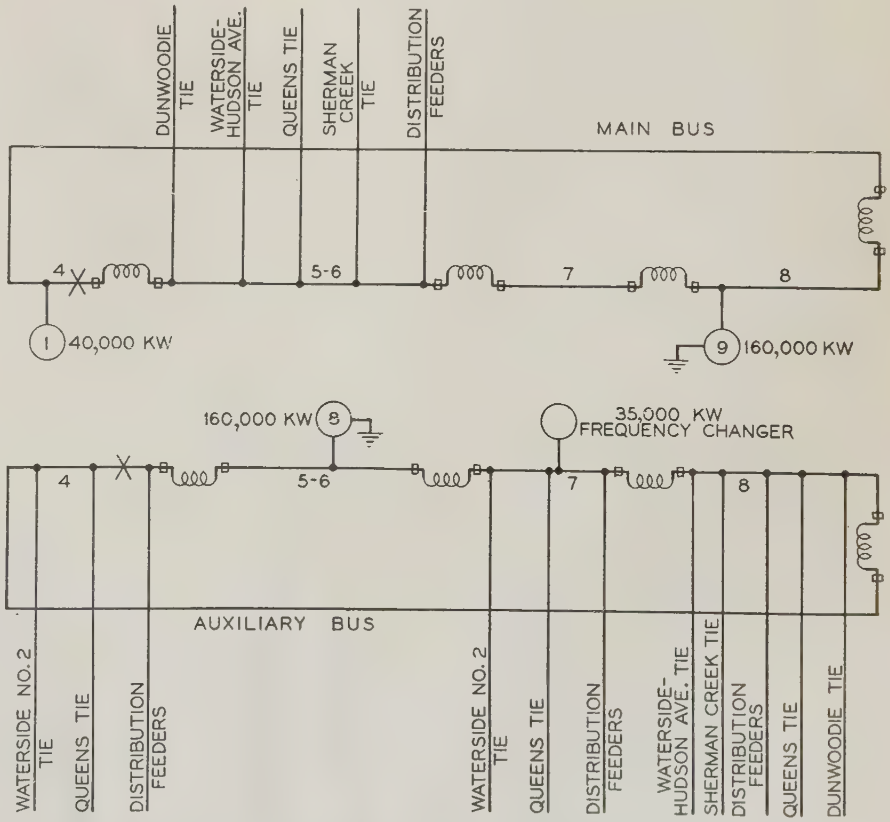
"The trouble occurred on January 15 at about 4:16 p.m. It was a dark rainy day. We had a system peak load coming on with no prospect of any appreciable drop in the load until after 10 o'clock. As you readily can see, conditions were about the worst imaginable. I thought it might be helpful to enable you to visualize the situation by preparing a diagram which shows the operating connections at Hell Gate at the time when the disturbance occurred. We were operating with the generating station set up in 2 independent busses, that is, the main bus had 2 machines connected to it: unit 1, a 40,000 kw machine, and unit 9, a 160,000 kw generator. There were also ties coming into the main bus, one 132 kv tie coming in from the Niagara-Hudson system, labeled Dunwoodie, and a 27 kv tie to Waterwide and Hudson Avenue (Brooklyn) stations. Ties to Sherman Creek station in the Bronx and other smaller ties through Queens also were connected to the bus.

"The arrangement on the auxiliary bus in general was somewhat similar to that on the main bus: machine 8, a 160,000 kw unit, and a frequency changer which connected to the 25 cycle section of Hell Gate. Ties on the auxiliary bus were similar in number and connections. There was one tie from the Niagara-Hudson system, and a 27 kv tie to Hudson Avenue, together with smaller ties to Hudson Avenue through Queens.

"Machine 9 is a cross compound unit, and the neutral was connected solidly to ground on the high pressure element. The same was true of machine 8. The trouble occurred initially as far as we can tell in section 4 of the bus. I might say right here that the bus construction in the Hell Gate station is of horizontal isolated-phase type. The trouble started on phase C, whether on main or auxiliary bus I am not prepared to say, but in any case the fault communicated immediately to the other bus. Immediately after the grounds occurred, the ties coming into the station, also the frequency changer, tripped off automatically so that the station bus was cleared from all connections to the remainder of the system. We still had generator 8 on the auxiliary bus and generator 9 on the main bus with their neutrals grounded feeding into the ground fault on section 4. They continued to do so until the neutral connections burned clear. The operators cleared the fault by taking machines off manually. We subsequently found in examining the bus that the fault had also developed in section 5–6 on A phase. The location where the fault in section 5–6 developed was removed by a considerable distance from the point where the initial failure occurred. It was separated as a matter of fact by several fire walls and fire doors. It doesn't seem at all probable that the gas generated from the arc in section 4 could have been communicated to section 5–6. It seems to me more likely that when neutrals burned clear on the generators, a surge was set up which caused the breakdown in section 5–6. The original ground being on C phase, whereas the other one developed on A phase, this seems to be a reasonable explanation of the failure in section 5–6. After the operators had had time to examine the busses, it was found that sections 7 and 8, which of course were separated from the other sections by circuit breakers, were in suitable condition to be restored to service, and that was done as soon as possible. I believe they were back in about a half hour after the trouble started.

"We supplied these 2 sections of the main bus by using one of the Niagara-Hudson ties and also the 27 kv ties that connected to Waterside and Hudson Avenue stations. It was impossible to restore the machines to service because the neutral connections had been damaged. In burning off the neutrals on machines 8 and 9, a fire was started from the oil in the neutral circuit breakers, and the blaze damaged the neutrals of 2 other machines which came into the same room. More detailed examination of the machines since has shown that they were generally all right with the exception of the high pressure element on unit 8. We found that the wedges on the field coils of this machine were somewhat displaced and bent. We are removing the rotor from the high pressure element now and we will know when completed how serious the damage was. The leads on generator 9 had the insulation burned off, and some of the supporting insulators were broken, I imagine as a result of the heavy stress from the short circuit.

"To give a better idea of the conditions on the system during and after the disturb-



Bus arrangement at Hell Gate generating station when disturbance on January 15, 1936, occurred; X indicates point where initial trouble is believed to have occurred

ance, I will explain that Hell Gate supplies in part Westchester County; it also supplies load in Manhattan, the Bronx, and Queens. The County of Westchester has an alternative supply coming in from the north, that is, the Niagara-Hudson 132 kv tie lines. When this trouble occurred, these 2 tie lines opened automatically at Hell Gate and left the Westchester system supplied from the north. Service in Westchester was maintained substantially without interruption at all times. A local disturbance occurred at Mount Vernon on account of a circuit breaker which blew up. The bus trouble at Mount Vernon caused an interruption which, I believe, was some 12 minutes in duration. Aside from that, service in Westchester was substantially normal.

"Before proceeding further I must explain that the Manhattan a-c network is separated into 3 distinct districts between which the network is completely sectionalized:

1. Battery to 59th Street.
2. 59th Street to 129th Street.
3. 129th Street to Harlem River.

"In the Bronx and the section of the Manhattan network north of 129th Street, we had alternative feeds from the Sherman Creek station. When the Hell Gate supply was completely interrupted, the capacity at Sherman Creek was not sufficient to carry the entire load. The result was that the steam pressure dropped at Sherman Creek and the frequency and voltage fell below normal. In about an hour we had service back substantially to normal in the Bronx and in the area north of 129th Street in Manhattan.

"We were able to use the Westchester system and the ties from the Niagara-Hudson system to good advantage in restoring service to the Bronx and Manhattan north of 129th Street. We did that by using some feeders which fed from Dunwoodie to New Rochelle, and from New Rochelle over two 45 kv feeders which came back to Sherman Creek. We placed these feeders on the auxiliary bus at Sherman Creek, and transferred a part of the Sherman Creek load to that bus. That assisted us in unloading Sherman Creek station sufficiently so that we could restore normal frequency and resynchronize the station with the rest of the system.

"In Manhattan south of 59th Stret, the system is fed not only from Hell Gate, but also from Hudson Avenue and Waterside stations. Service there was substantially unaffected. The situation in Queens was the same. The Queens feeders at Hell Gate opened, but the remaining feeders from Hudson Avenue were sufficient to carry the load so that service in Queens was substantially unaffected. The district that was hit most severely was the one from 59th Street to 129th Street. The d-c system in this area was not affected, however, and it still carried some 60 per cent of the load there.

"When we put the feeders to the network area between 59th and 129th streets back in service at Hell Gate, on sections 7 and 8 the number of feeders put into operation was not sufficient to carry the load, and the result was that network transformers became badly overloaded and started blowing fuses. Even when we put some additional feeders back we were unable to carry load. The service was restored by sectionalizing the area out in the street. We opened up service switches in several buildings to reduce the load. Then as feeders came back, we restored service to the several areas successively by putting in fuses simultaneously on the secondaries of the network transformers. Although the process of clearing up the bus at Hell Gate in section 4 and section 5–6 required a considerable amount of time, we were able to get section 4 back in service by about 10:30 p.m. and section 5–6 at about 2:30 a.m. We were able to get back a considerable number of feeders which normally operated on those sections a good deal earlier by an expedient use of available feeder connections.

"In the area between 59th and 129th Streets where the interruption to service was most serious, some 40,000 customers were involved. Since this 40,000 compares with a total of 2,000,000 customers on the entire system, we feel that the extent of the trouble was not quite as large as it might seem. The connections to our other stations and to the Niagara-Hudson system were very helpful in restoring service, as I have shown, and in many cases prevented interruption in an entire area completely."

A.I.&S.E.E. Spring Engineering Conference. Plans are being completed for the annual conference sponsored by the combustion engineering division of the Association of Iron and Steel Electrical Engineers, to be held at the Ohio Hotel, Youngstown, Ohio, April 22–23, 1936. Among the subjects to be discussed are: the cleaning of blast furnace gas, refractories, and other subjects related to the blast furnace, open hearth, and rolling mills. As part of the program, an inspection trip will be made to the new hot strip mill of the Carnegie-Illinois Steel Corporation recently completed and put into operation at McDonald, Ohio. This mill is capable of a production of 30,000 tons per month.

Elwood Mead, Reclamation Commissioner Dead. Since 1924 Commissioner, Bureau of Reclamation, U.S. Department of the Interior, and long incontestably recognized as an irrigation authority, Dr. Elwood Mead died January 26, 1936, at the age of 78, at his home in Washington, D. C. A native of Patriot, Ind. (1868) Doctor Mead received his education at Purdue University, and subsequently (1884) became the first American professor of irrigation, at the Colorado State College of Agriculture. Serving also for a year as assistant state engineer, he was called in 1888 to Wyoming as territorial engineer, remaining in the employ of the territory and the subsequent state for 11 years. From 1899 until 1907, Doctor Mead concurrently served the U.S. Department of Agriculture as chief of the irrigation and drainage division, and the University of California as professor of irrigation, going to Australia in 1907 as chairman of the State Rivers and Water Supply Commission of Victoria. Rejoining the University of California faculty in 1915, Doctor Mead also served as chairman of the State Land Settlement Board. As a member (1923–24) of a fact-finding and investigational

First Water Through Operating Channel at Boulder Dam

On Monday, February 10, the lower valve in the intake tower nearest to Boulder Dam on the Arizona side was opened, admitting water to pass for the first time through the 30 feet steel penstock to the normal downstream by-pass outlet on the Arizona side, whence it is spilled into the river as shown, through one of the several outlets there provided. Each of these openings is controlled by a 6 foot needle valve. To supply water users lower down the river, the maintenance of a certain minimum stream flow is required. Heretofore, during construction, this has been supplied through the number 1 Nevada diversion tunnel, the sealing plug in which was fitted with 4 4 by 6 foot discharge openings equipped with control valves. When the Boulder generating plants are not in operation, the required stream flow will be maintained through the channel now in service, and, when necessary, through a duplicate channel on the Nevada side. The roofs of the power house structures may be seen in the immediate foreground. The picture was taken from the top of the dam by D. M. Simmons (A'22, F'28) chairman of the A.I.E.E. power transmission and distribution committee.

March 1, 1936, less than 5 years after work was started, was set by the Department of Interior as the date of acceptance of the dam and the power house and termination of the actual construction work.

board appointed by the Secretary of the Interior, Doctor Mead contributed very largely to the preparation of the board's ultimate report and recommendation for extensive changes in reclamation legislation and practice. This work led to the immediate appointment of Doctor Mead as commissioner of the Bureau of Reclamation in 1924. Doctor Mead was a past director (1903–05) of the American Society of Civil Engineers. Both the University of Michigan (1925) and the University of Wyoming (1934) had conferred upon him honorary doctorate degrees.

Waterside Station to Be Modernized

An expenditure of about $5,000,000 is contemplated by the New York (N. Y.) Edison Company, Inc., for the modernization of its Waterside generating station to provide for a heavily increased demand for power. Waterside is one of the older generating stations in the New York Edison system. It now has 146 boilers with a total capacity of 5,256,000 pounds of steam per hour, and 19 generators of 376,200 kw capacity. This equipment was installed at various times betwen 1900 and 1924.

The modernization program calls for the retirement of 36 of the existing boilers in the station and 3 of the present turbogenerators. Two new boilers will be installed, each having a capacity of 500,000 pounds of steam per hour at a pressure of 1,500 pounds per square inch and a temperature of 900 degrees Fahrenheit. The steam from these new boilers will be used to operate a new 50,000-kw 60-cycle turbogenerator. The steam will exhaust from the machine at 200 pounds pressure and will then pass through existing low pressure turbines to the condenser, generating an additional 65,000 kw.

It is expected that the rate of fuel consumption of the plant after modernization will be approximately half the present rate, and that the fuel consumption will be reduced about 100,000 tons per year. The work of installing the new equipment is expected to be completed about April 1937.

New York Museum of Science and Industry in New Quarters

On the evening of February 11, 1936, the New York (City) Museum of Science and Industry was formally opened in its new quarters at 30 Rockefeller Plaza, Radio City. The opening was marked by a special program which included talks by Dr. Frank B. Jewett (A'03, F'12, and a past-president) president of the board of trustees of the museum, Fiorello LaGuardia, mayor of the city of New York, and such prominent scientists as Dr. Albert Einstein, Dr. Irving Langmuir, and Dr. Robert A. Millikan (M'22, HM'33). As a special feature of the program, Sir William Bragg, distinguished British scientist, while seated at the desk in London used by Michael Faraday in working out his epoch-making experiments in electromagnetism, lighted a candle which initiated an electrical impulse; this impulse was sent out by radio and was received at the museum where it lighted the first incandescent electric lamp made by the Westinghouse company; by means of photoelectric devices, this lamp in its turn lighted a battery of 40 new mercury vapor lamps at the museum.

In describing the museum and its functions, Doctor Jewett said that the museum was initiated through a gift from the late Henry R. Towne, who "saw the necessity in our mechanistic world of some agency capable of imparting to those who are not scientists and engineers an insight at once into the power as well as the limitations of technology when applied to the peaceful arts." "It was with the idea of facilitating the acquisition of . . . simple fundamental knowledge of science as applied to industry that the original Museum of Science and Industry was started," Doctor Jewett continued. ". . . the museum was not designed to be a substitute either for the circus or the college, technical school or university. It was designed as a place in which could be displayed in simple logical sequence some of the more important applications of science to industry and human intercourse."

Among the various exhibits are: various types of mechanisms; steam engines of various vintages; equipment used in air, water, rail, and automotive transportation, electrical devices and machinery; communication equipment of various types; textile mills; and housing. In addition to the permanent exhibits, there will be special temporary exhibits from time to time.

A.S.A. Elects Officers. At the annual meeting of the American Standards Association held in New York, N. Y., December 11, 1935, Dana D. Barnum, president of the Consolidated Gas Company, Boston, Mass., was elected president for the ensuing year, and Edmund A. Prentis, of Spencer, White and Prentis, Inc., New York, N. Y., was elected vice president. J. C. Irwin, representing the Association of American Railroads, was re-elected chairman of Standards Council, and F. M. Farmer (A'02, F'13) vice president, Electrical Testing Laboratories, New York, N. Y., was re-elected vice chairman. Howard Coonley, president for the preceding year, pointed out in his annual report that 55 new national standards and 16 revisions were approved during the year, and that the association had been reorganized to co-ordinate more effectively the increasing number of projects. Increasing support by industry enables the association to operate on a balanced budget without the necessity of having funds underwritten, for the first time in 18 years.

Midwest Power Engineering Conference. The 6th Midwest Power Engineering Conference will be held April 20–24, 1936. Officers elected for this conference are: F. D. Chase, *president;* J. R. VanPelt, *chairman;* O. A. Anderson, F. R. Innes (A'25, M'26), J. E. Kearns (A'07, M'21), G. E. Pfisterer, and K. A. Auty (A'12, M'17). Official hotel meeting headquarters will be at the Palmer House, Chicago. Afternoon sessions will be held at the International Amphitheater, where the Midwest Power Show will be held. Among the sessions already planned are those covering prime movers, refrigeration, electrical transmission and application, ventilation, and coal utilization. The conference will be sponsored by local sections of the national societies of civil, electrical, mechanical, and refrigerating engineers, the Edison Electric Institute, Western Society of Engineers, and National Safety Council. Meetings are open to all persons interested regardless of membership in sponsor societies.

A.S.C.E. Elects Officers. The American Society of Civil Engineers, at its annual meeting held in New York, N. Y., January 15–16, announced the names of new officers of the society for 1936. For president, D. W. Mead (A'11, F'13) member of the firms of Mead and Seastone, Madison, Wis., and of Mead and Scheidenhelm, New York, N. Y., has been elected. For 28 years preceding his retirement from teaching in 1932, he was professor of hydraulics and sanitary engineering at the University of Wisconsin. The 2 vice presidents elected, one to serve from each of 2 zones, are: E. P. Lupfer, consulting engineer, Buffalo, N. Y., and H. W. Dennis, chief civil engineer, Southern California Edison Company, Los Angeles. To serve as directors, the following 6 men have been elected: C. S. Proctor of Moran and Proctor, consulting engineers, New York, N. Y.; J. K. Finch, professor of civil engineering and head of the department, Columbia University, New York, N. Y.; C. E. Myers, consulting engineer, Philadelphia, Pa.; R. A. Hill, member of Quinton, Code, and Hill—Leeds and Barnard, consulting engineers, Los Angeles, Calif.; L. L. Hidinger, president of Morgan Engineering Company, Memphis, Tenn.; and E. P. Arneson, consulting engineer, San Antonio, Texas.

American Engineering Council

Plans for 1936 Divide Committees Into 4 Groups

Following the annual meeting of Council, reported in the February issue (pages 215–16) President Potter and the staff have reviewed the past activities of both committees and staff with the thought of giving a common sense of direction to both delegates and the member organizations of the work for the year ahead.

The work of Council is carried out first through the agency of a paid staff at the Washington headquarters, and second, by a group of committees appointed annually by the president. Long standing policies of Council call for no new expression by committees, but the considered opinion of the members of Council is developed through

the year by its several committees and provides the basis for staff action.

Last year, the committee on public affairs was organized in such a way that the chairmen of subcommittees on questions of public moment became in fact the general committee on public affairs under the general chairmanship of F. J. Chesterman (A'20, F'22). The intent of these committees is to establish principles for the staff handling of details. The success of this plan led to the similar organization of committees in other fields of action of Council, and the following plan has received the approval of the executive committee.

The various committees of Council have been divided into 4 groups. The first consists of the "committees on public affairs," and comprises the following subcommittees:

1. Aeronautics.
2. Public works administration.
3. Relation of engineers in private practice to government.
4. Conservation and utilization of national resources.
5. Patents
6. Surveys and maps.
7. Regional activities.
8. Rural electrification.

The second group is known as the "committees on engineering and economic surveys." Under this head, the following subcommittees have been projected:

1. The balancing of economic forces.
2. Special studies.

The third group has been called "committees on programs for united action of member organizations"; under this group the following subcommittees have been approved:

1. Publicity for the profession.
2. Economic status.
3. Merit system in the public service.
4. Survey of the engineering profession.

It may be observed that committees 1, 2, and 3 of the foregoing group are new. The object of these new committees is to seek to co-ordinate for a common sense the direction activities now being handled in some instances by special committees of member organizations. The committees of Council are not intended to supplant the effective work of such committees, but rather to provide a common meeting ground for all interested in securing larger accomplishment through collective action, wherever this is practicable.

The fourth group of committees constitutes the "American Engineering Council operating committees," and includes:

1. The executive committee.
2. The finance committee.
3. The membership and representation committee.
4. Constitution and by-laws.
5. Publicity for American Engineering Council

From time to time, the activities of these various committees will be reported in these columns.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Capacitor Motor With Double Cage Rotor

To the Editor:

Referring to the letter of Mr. A. F. Puchstein in the January issue of ELECTRICAL ENGINEERING (pages 121–2) there was no intention to imply that a double squirrel cage capacitor motor would not operate satisfactorily under any condition. The writer intended to outline some of the limitations of the double cage capacitor motor which appeared to bar it as a general purpose motor even though it had been proposed over 20 years ago. Also the point was brought out that where it is desired to start with a large starting torque and a minimum of starting current, and with low slip, high power factor, and efficiency at running, the repulsion capacitor motor, which likewise is not a general purpose motor, is superior to the double cage capacitor motor. However, there was no intention to imply that there was no possible condition where the double cage capacitor motor might not find favor.

As to the double cage rotor, Mr. Puchstein states that its lower rotor resistance may make up for the losses due to the higher flux required. This is true in regard to squirrel-cage-starting capacitor motors, as comparatively high rotor resistance is necessary to provide starting torque. However, with repulsion starting, low rotor resistance, as well as low reactance, is desirable, and neither high rotor resistance nor high flux is required, thereby increasing both the efficiency and power factor of the repulsion capacitor motor.

Mr. Puchstein also states that the repulsion capacitor motor has more leakage reactance, higher resistance, higher cost, and more things to go wrong.

As to leakage reactance, the short-circuited repulsion rotor may have more than a low-reactance single-cage rotor, but the leakage reactance of the short-circuited repulsion rotor is much less than that of the double cage rotor.

As to rotor resistance, the repulsion rotor resistance, as well as the reactance should be low, since neither serve any useful purpose with repulsion starting. A high resistance repulsion rotor would be a poor design.

As to costs, no doubt the repulsion capacitor motor in small sizes will cost more than a squirrel-cage capacitor motor; but, especially in the larger sizes for providing exceedingly high starting torque with low starting current and operating at the highest efficiency and power factor, the repulsion capacitor motor will give characteristics that the double squirrel cage does not duplicate, will be more reliable, and probably will have no greater over-all costs than the double cage form when the starting, switching, and running accessories are included.

As to reliability, the repulsion induction motor is now used whenever the operating conditions are extremely severe, and it has given good account as to reliability. As the repulsion capacitor motor is simply a repulsion induction motor with a capacitor and capacitor phase to increase the output and improve the power factor and efficiency, its reliability is the same as that of the repulsion induction motor. In fact, it would appear to be more reliable than any squirrel-cage capacitor motor for the reason that should the capacitor become disabled the squirrel cage motor cannot start, while the repulsion capacitor can start and operate without the capacitor, as a repulsion induction motor, carrying a substantial part of its load, giving emergency service while the capacitor is disabled.

Mr. Puchstein further states that the leakage reactance of the low resistance component of the double squirrel cage rotor does not manifest itself at starting and lower speeds. As the reluctance through the rotor outside the low resistance cage is much higher than through it when running, the effect at starting is that of a higher reluctance magnetic circuit. This increases the lagging exciting current at starting, thereby requiring larger starting capacitor than would be needed if the low resistance cage were removed. As a matter of fact, the low resistance cage does have a bearing on the starting capacitor.

Yours very truly,

EDWARD BRETCH (M'19)

The Advance Electric Co.,
St. Louis, Mo.

Similarity Relations in Electrical Engineering

To the Editor:

In the June 1935 issue of ELECTRICAL ENGINEERING (p. 683–4) Professor Ernst Weber offers a correction to the paper "Similarity Relations in Electrical Engineering" (ELEC. ENGG., March 1935, p. 268–72.) May we humbly point out that not only is the correction invalid, but the need for it is contradicted by the very authority (P. W. Bridgeman) cited.

Yours very truly,

J. G. BRAINERD (A'32)
J. NEUFELD

Moore School of Electrical Engineering,
University of Pennsylvania, Philadelphia

Personal Items

A. M. MacCutcheon Nominated for Presidency

Alexander Morton MacCutcheon (A'12, M'15, F'26, and past director) engineering vice president of The Reliance Electric and Engineering Company, Cleveland, Ohio, has been nominated for the presidency of the A.I.E.E. for the 1936–37 term. He was born at Stockport, N. Y., December 31, 1881, and was graduated from the State Normal College at Albany in 1901. After teaching mathematics and science in high schools until 1904 he entered the electrical engineering course at Columbia University, from which he was graduated in 1908. While employed by the Crocker-Wheeler Company, Ampere, N. J., from 1909 to 1914 Mr. MacCutcheon was successively in charge of engineering estimates, all estimates and proposals, and the drafting room, and also spent several months on alternator design. In 1914 he took charge of all new design work for The Reliance Electric and Engineering Company. He was appointed chief engineer in 1917, and in the fall of that year entered the U.S. Navy. At the time of his release in 1919 he was lieutenant in charge of fire control on the U.S.S. "Louisiana." Early in that year he returned to his former position, and the following year was elected a director of the Reliance company. Since 1923 he has held the position of vice president in charge of engineering. Mr. MacCutcheon was a director of the Institute 1928–32, and has served on the following committees: general power applications, 1916–18, 1924–33 (chairman 1925–28); electrical machinery, 1924–34; meetings and papers (now technical program) 1925–29; electric welding, 1928–30; applications to iron and steel production, 1928–33; Edison Medal, 1929–31; and executive, 1930–31. He is now chairman of the Lamme Medal committee on which he has served since 1934, and is a member of the standards committee on which he has served since 1922 (chairman 1931–34). As Institute representative he served on the assembly of the American Engineering Council (1932–33) and has been on the standards council of the American Standards Association since 1932, on the electrical standards committee of the American Standards Association since 1931, and on the U.S. national committee of the International Electrotechnical Commission since 1931. He was a member of the 1916 summer convention committee, and vice chairman of the 1932 summer convention committee, being largely responsible for bringing that convention to Cleveland. His activities in the Cleveland Section include chairmanship of several of its committees and a term (1920–21) as chairman of the Section. At present he is a member of the Section advisory board. In 1917 Mr. MacCutcheon became a member of the Association of Iron and Steel Electrical Engineers. He has served on various committees for that organization and is recognized as an authority on the subject of motor applications for steel mill auxiliaries. Since 1921 he has been a member of Cleveland Engineering Society, serving as a director (1923–25) and on many committees. He has presented papers before the Institute, the Association of Iron and Steel Electrical Engineers, The American Society of Mechanical Engineers, and the American Drop Forging Institute. In 1912 Mr. MacCutcheon became a member of the Electric Power Club, which later was absorbed by the National Electrical Manufacturers' Association. In the former he was chairman of the technical standardization committee, and in the latter organization was one of the leaders in bringing about the standardization of uniform motor mounting dimensions. At present he is a member of the general engineering committee of the National Electrical Manufacturers' Association, and represents that organization on the rotating machinery sectional committee of the American Standards Association.

Vice Presidential Nominees Are Blackwell, Stevens, Harding, Blaisdell, Rogers

Otto Bernard Blackwell (A'08, M'13, F'17) manager of staff departments, Bell Telephone Laboratories, Inc., New York N. Y., has been nominated to serve the Institute as vice president representing the New York City District (number 3). Mr. Blackwell, who was born at Bourne, Mass., August 21, 1884, received the degree of bachelor of science from Massachusetts Institute of Technology in 1906. Shortly afterward he entered the engineering department of the American Telephone and Telegraph Company at New York. In 1914 he became transmission and protection engineer, and in 1919 with the formation of the department of development and research, was made transmission development engineer. When the department was transferred to the Bell Telephone Laboratories in 1934 Mr. Blackwell was appointed director of transmission development. In June 1935 he was appointed to his present position as manager of staff departments. While this last appointment has broadened his responsibilities to cover nontechnical work, he continues his technical interests in that the transmission development department and protection department are among those which come under his supervision. His individual contributions to the art have been to the practical theory of transmission and crosstalk and to many problems which have arisen in transmission development, such as methods of reducing crosstalk in duplex cables, improvements in telephone repeater balance, and methods of transmission testing in the operating plant. The development departments of which he has had charge have played an important part in the outstanding developments which have taken place in telephone transmission, including the application of repeaters to open wire lines, the development of long distance small gauge repeatered cables, the application of carrier to open wire lines, and the present development of wide band transmission over cable circuits. Mr. Blackwell is the author of several technical papers, and shared with a co-author the 1931 A.I.E.E. national prize for best paper in engineering practice. He was a member of the Institute's meetings and papers committee (now technical program) 1922–25, and served on the communication committee (including its predecessor, the committee on telephony and telegraphy) 1918–26, being chairman 1922–25. This year he is again a member of this committee. During the year 1926–27 Mr. Blackwell was secretary of the New York Section. He is a fellow of the Institute of Radio Engineers and of the Acoustical Society of America, a member of the standards council of the American Standards Association representing the telephone group, and a member of the plant co-ordination committee and the joint subcommittee on development and research of the Edison Electric Institute and Bell telephone system; he also holds membership in the Railroad-Machinery Club of New York and the North Hempstead Country Club.

Alexander Chilson Stevens (A'18 M'26, and director) in charge of educational sales, General Electric Company, Schenectady, N. Y., has been nominated to serve the Institute as vice president representing the North Eastern District (number 1). Mr. Stevens was born at Riverhead, N. Y., October 9, 1883, and attended schools in Middletown, Conn., and White Plains, N. Y. He then studied for 2 years at Wesleyan University and 3 years at Cornell University, receiving the degree of mechanical engineer in electrical engineering from the latter in 1907. From 1908 to 1912 he was an instructor in physics, electricity, and descriptive geometry at Wesleyan University, and from 1913 to 1917 was an instructor in electrical engineering at Cornell University. In 1917 he entered the transformer engineering department of the General Electric Company at Pittsfield, Mass., and 2 years later was transferred to the transformer sales department. Since 1925 he has been at Schenectady as head of the educational section of the central station department, having charge of all sales to educational institutions. Mr. Stevens was elected a director of the Institute in 1932 for a term of 4 years, and is a member of the committees on education, electric welding, applications to iron and steel production, applications to mining work, and Edison Medal. During the year 1925–26 he was a member of the special committee on Institute prizes. Since the organization of the North Eastern District in 1922 he has been its secretary. While at Pittsfield he was a member of the executive committee of that Section, serving also as chairman of several standing committees and in the offices of secretary and vice chairman elect. Mr. Stevens is a member of the Society for the Promotion of Engineering Education, Eta Kappa Nu, Delta Kappa Epsilon, Cornell Club of New York, and several Masonic fraternal organizations.

Charles Francis Harding (A'06, M'12, F'14) head of the school of electrical engineering and director of the electrical engineering laboratories of Purdue University, West Lafayette, Ind., has been nominated to serve the Institute as vice president repre-

senting the Great Lakes District (number 5). He was born at Fitchburg, Mass., September 11, 1881, and was graduated in 1902 from Worcester Polytechnic Institute, which awarded him the degree of electrical engineer in 1910. His early engineering experience was gained in the testing department of the General Electric Company at Schenectady, N. Y. (1902), and as electrical engineer for the Worcester and Southbridge Railway Company, Worcester, Mass. (1902–04), and for the D. and W. Fuse Company, Providence, R. I. (1904–05). During the year 1905–06 Doctor Harding was acting professor of electrical engineering at Cornell University, and the following year was assistant electrical engineer of the Stone and Webster Engineering Corporation, Boston, Mass. In 1908 he was appointed to his present position at Purdue University, where in addition to his regular duties he has served as a consulting engineer. Having specialized in extra-high-potential measurements and research, he has developed one of the few large high voltage laboratories located at educational institutions, and throughout a period of 25 years has presented several Institute papers and many discussions upon associated subjects. He also is the author of 2 books and many other technical articles. Doctor Harding has been a member of the following Institute committees: student branches, 1916–26 (chairman 1918–23); sections, 1918–23; general power applications, 1926–30; electrical machinery, 1929–33; and Edison Medal, 1929–33. Since 1933 he has served on the Lamme Medal committee, and since 1932 on the power transmission and distribution committee, taking part in the work of the lightning protection and sphere gap subcommittees of the latter. He was also Institute representative on the committee of the Society of Industrial Engineers on the elimination of fatigue. For the 1935 Great Lakes District meeting Doctor Harding served as chairman of the program committee and contributed largely to the success of that meeting. He is a member and past vice president of the Society for the Promotion of Engineering Education, American Electric Railway Association, American Association of University Professors, society of the Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and others.

Leonard Tibbetts Blaisdell (A'20, M'22) southwestern district manager, General Electric Company, Dallas, Texas, has been nominated to serve the Institute as vice president representing the South West District (number 7). Mr. Blaisdell was born at Carlisle, Mass., October 6, 1886. He was graduated from the marine engineering course at the Massachusetts Nautical Training School in 1904, and entered the student course of the General Electric Company at Lynn, Mass., serving in the testing department until 1907. He was then transferred to the construction department, supervising the installation of power plant equipment until 1911. During this period as construction engineer Mr. Blaisdell supervised the installation of steam turbines and electrical equipment on many of the battleships, cruisers, and submarine chasers of the United States Navy built at shipyards along the Atlantic coast, and served as the engineer on many of the trial trips. He also performed the same duties in connection with the installation of steam turbines and electrical equipment on ships of the merchant marine. From 1911 to 1917 he served as commercial engineer in the Baltimore, Md., office of the General Electric Company, and in 1917 was transferred to the Washington, D. C., office to follow the various activities of the federal government. He served as manager of this office until 1923, when he was transferred to his present position at Dallas. Mr. Blaisdell was chairman of the Washington Section in 1923, and of the Dallas Section in 1930.

Clarence Ellams Rogers (A'11, M'32) chief engineer of the Pacific Telephone and Telegraph Company in the Washington-Idaho area with headquarters at Seattle, Wash., has been nominated to serve the Institute as vice president representing the North West District (number 9). He was born at Albuquerque, N. M., October 31, 1887, and was graduated from the University of New Mexico in 1909 with the degree of bachelor of arts. During 1909–10 he was John W. Mackay, Jr., fellow in electrical engineering at the University of California, where he received the degree of master of science in 1910. While obtaining his education he was employed during vacations by the Mutual Automatic Telephone Company at Albuquerque, Colorado Telephone Company, The Atchison, Topeka and Santa Fe Railroad, and the Automatic Electric Company. From 1910 to 1912 he was employed by the Bay Cities Home Telephone Company, serving as central office repairman, cable tester, foreman, and superintendent of equipment. He was engaged by the Pacific Telephone and Telegraph Company in 1912, and until 1916 served in the plant department as Coast district toll wire chief, Central California division transmission inspector, and plant general office staff assistant on leased telegraph facilities. In 1916 Mr. Rogers was transferred to the general engineering department at San Francisco, Calif., and was assigned successively as toll switchboard engineer, station and private branch exchange engineer, and equipment studies engineer. He was transferred to the Western Electric Company at Chicago, Ill., in 1919, then to the engineering department of that company at New York, N. Y., where his work was with the panel dial equipment. Returning to The Pacific Telephone and Telegraph Company in 1920, he became resident engineer at Seattle during the introduction of dial equipment there, and 5 years later was appointed equipment and building engineer for the Northern California and Nevada area with headquarters at San Francisco, having general supervision of the engineering and design of central office and station equipment and buildings until 1930, when he was appointed to his present position. Mr. Rogers has been active in Institute affairs, having served on the executive committees of the San Francisco and Seattle Sections and as chairman of the Seattle Section during the 1934–35 term during which he was largely responsible for organizing the 1935 Pacific Coast convention held in Seattle last summer. He was a member of the national nominating committee in 1931.

McEachron, Powel, Sorensen Nominated for Institute Directorships

Karl Boyer McEachron (A'14, M'20) research engineer in charge of high voltage practice, General Electric Company, Pittsfield, Mass., has been nominated to serve the Institute as a member of its board of directors. He was born at Hoosick Falls, N. Y., November 17, 1889, and was graduated from the electrical engineering course at Ohio Northern University in 1913. For the following year he was on special test with the General Electric Company at Pittsfield, and during the next 4 years he was an instructor in electrical engineering at Ohio Northern University. From 1918 to 1922 he was associated with the staff of Purdue University, acting as instructor in electrical engineering and as research associate in the engineering experimental station; receiving the degree of master of science in electrical engineering in 1920. During these years he was interested particularly in the fixation of atmospheric nitrogen through the use of high voltage discharges. In 1922 Mr. McEachron returned to the General Electric Company at Pittsfield, heading a research group in connection with the development of lightning arresters and associated protective equipment. The first cathode ray oscillogram of lightning arrester performance is said to have been taken under his direction in August 1924. In 1933, following the death of F. W. Peek, Jr. (A'07, F'25), Mr. McEachron was appointed to his present position, in which he is responsible for the operation of the high voltage engineering laboratory at Pittsfield. In his present capacity Mr. McEachron supervises lightning investigation projects both in the field and in the laboratory. For his investigations, resulting in the production of a new resistance material, he was awarded the Edward Longstreth Medal of the Franklin Institute in 1935. Many papers on the subject of lightning have been presented to the Institute by Mr. McEachron. He was a member of the Institute's committee on electrophysics 1926–32, and has served on the committee on protective devices since 1933, having previously been a member of this committee 1926–28.

Charles Alfred Powel (M'20) manager of the central station engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been nominated to serve the Institute as a member of its board of directors. Mr. Powel was born at Rouen, France, July 29, 1884, of Welsh parentage. He was educated in England and Switzerland, graduating in 1905 from the Institution of Technology of Canton Bern. In the same year he entered the application engineering department of Brown, Boveri and Company in Baden, Switzerland. In 1911 he was sent to Japan by that company as resident engineer, remaining there until 1915 when war conditions made business impossible. He returned to England and joined the civil branch of the Ordnance Department, being transferred in 1916 to the inspection service of the British War Mission in the United States. He was discharged in 1919 and joined the central station engineering department of the Westinghouse Electric

and Manufacturing Company, of which department he is now manager. Mr. Powel has presented a number of papers before the Institute and other associations. He has been a member of the Institute's power generation committee since 1933, and in 1930–31 was chairman of the subject committee on grounding. For a number of years he has been active on the various committees of the Pittsburgh Section and is at present chairman of that Section.

Royal Wasson Sorensen (A'07, M'13, F'19, and past vice president) professor of electrical engineering and head of the department at California Institute of Technology, Pasadena, has been nominated to serve the Institute as a member of its board of directors. He was born at Alta Vista, Kan., April 25, 1882, and from the University of Colorado received the degrees of bachelor of science in electrical engineering (1905) and electrical engineer (1928). He entered the test department of the General Electric Company at Schenectady, N. Y., in 1905 as a student engineer, and became foreman the following year. He was then transferred to the commercial section of the transformer engineering department, and in 1908 was transferred to the Pittsfield, Mass., works. Two years later he accepted the position of associate professor of electrical engineering at Throop Polytechnic Institute, now California Institute of Technology. In 1911 he was made professor, a position which he has held continuously since that time. Professor Sorensen has been engaged also in a consulting practice. During 1913–17 was engaged by the Pacific Light and Power Corporation in connection with the then record breaking 150 kv Big Creek transmission system. He has been engaged in research on a vacuum type of circuit breaker (1929–30) and in special work in the research division of the General Electric Company during the same years, and is a holder of United States and foreign patents covering high voltage circuit breakers. From 1917 to 1932 he was consulting engineer for the U.S. Electric and Manufacturing Company of Los Angeles, Calif. He has served for some time as a member of the board of consulting engineers for the Metropolitan Water District of Southern California. Professor Sorensen has made several contributions to the Institute's technical literature, and has served on the committees on research (1923–30), instruments and measurements (1927–30), student branches (1927–28), and education (1924–28); since 1934 he has again been a member of the committee on education, and since 1933 a member of the Lamme Medal committee. He was a vice president of the Institute 1933–35, and has served the Los Angeles Section as secretary (1919–20) and as chairman (1920–21). In 1924 he was chairman of the Pacific Coast convention committee and is now chairman of the 1936 summer convention committee. He is counselor of the Student Branch at California Institute of Technology. Professor Sorensen is a member of Society for the Promotion of Engineering Education, American Association of University Professors, Los Angeles Engineering Council, and Athenaeum Club (Pasadena); he is president of the Pasadena Young Men's Christian Association and the Pasadena Engineer's Society; he is also past-chairman of the joint technical society and the Sigma Xi and Tau Beta Pi clubs of Los Angeles.

W. I. Slichter
Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12, National treasurer and past vice president) professor of electrical engineering at Columbia University, New York, N. Y., has been nominated to succeed himself as treasurer of the Institute. He was born at St. Paul, Minn., May 7, 1873, and received the degree of electrical engineer from Columbia University in 1896. Professor Slichter has devoted his energies generously to the Institute throughout a long period; since 1914 he has been an active member of 18 different Institute committees and has represented the Institute on 6 joint bodies. At present he is a member of 7 committees and a representative on 4 bodies. A full biographical sketch of Professor Slichter was published in Electrical Engineering for January 1931, page 56.

Vannevar Bush
to Receive Lamme Medal

Vannevar Bush (A'15, M'19, F'24) vice president of Massachusetts Institute of Technology and dean of the school of engineering, Cambridge, Mass., has been awarded the Lamme Medal of the A.I.E.E. for 1935 "for his development of methods and devices for application of mathematical analysis to problems of electrical engineering." Doctor Bush was born at Everett, Mass., March 11, 1890. In 1913 he was graduated from Tufts College, and in 1916

VANNEVAR BUSH

was awarded the degree of doctor of engineering from Massachusetts Institute of Technology and Harvard University. In 1932 he received the honorary degree of doctor of science from Tufts College, and he is now a member of the board of trustees of that college. Following graduation from Tufts College he entered the testing department of the General Electric Company, and the next year was an instructor in mathematics at Tufts College. In 1915 he engaged in graduate study at M.I.T., and the following year returned to Tufts as assistant professor of electrical engineering. During 1917–18 Doctor Bush carried on research work in submarine detection for the United States Navy; then until 1923 was associate professor of electric power transmission at M.I.T. From 1917 to 1922 he was also consulting engineer for the American Radio and Research Corporation. In 1923 he was appointed professor of electric power transmission, holding this title until appointed to his present position in 1932. Doctor Bush long has been interested in the design of analyzing instruments and is internationally known for his achievements in this field. For one development he was awarded the Levy Medal of the Franklin Institute in 1928. One intricate calculating machine, the differential analyzer, which is capable of solving complex ordinary differential equations, was built under his personal direction; other models of this machine have now been built in various parts of the world. Doctor Bush also directed the design and construction of the "network analyzer," a device for accurately reproducing and studying the operating characteristics of power networks under the most satisfactory conditions. He has carried on important studies of transients in machines and in interconnected power systems, and is known for his contributions to the development of thermionic and gaseous tubes. In the introduction of operational methods of circuit analysis to engineering problems he was one of a group of pioneers. Doctor Bush is a director of the Spencer Thermostat Company and of Raytheon, Inc., and is a member of the corporation of Massachusetts Institute of Technology. He is the author of many technical articles and of "Operational Circuit Analysis," and, jointly with W. H. Timbie (A'10, F'24), of "Principles of Electrical Engineering." The Institute committees on which he has served include research (1924–30); electrophysics (1924–33, chairman 1931–33); power transmission and distribution (1925–27, 1928–29); education (1928–29); and technical program (1929–33). He is now a member of the Edison Medal committee, and representative on the division of engineering and industrial research of National Research Council. Doctor Bush is a fellow of the American Academy of Arts and Sciences and American Physical Society, and a member of the Society for the Promotion of Engineering Education, National Academy of Sciences, Phi Beta Kappa, Alpha Tau Omega, Sigma Xi, and Tau Beta Pi.

F. A. Lewis (A'31, M'35) since 1931 an assistant editor on the staff of Electrical Engineering has been appointed associate editor. A native (1903) of Luzerne County, Pa., Mr. Lewis graduated in 1926 from Syracuse (N. Y.) University with the degree of electrical engineer. During his junior and senior years he acted as instructor in mechanical drawing and during the summer of 1925 was engaged in transmission and substation maintenance work for the Pennsylvania Power and Light Company, Wilkes-Barre. Upon graduation, Mr. Lewis became affiliated with the New York Edison Company, first in the test department and later in the transmission and distribution

department. While in the test department (1926–29) Mr. Lewis was in responsible charge of special laboratory and field investigations in connection with a-c and d-c electrolysis, special studies and surveys made in connection with the feeder distribution system, and tests in connection with radio interference, including the development of required equipment. He also assisted in experimental and developmental work pertaining to carrier current control of certain power system equipment. In the transmission and distribution department (1929–30), Mr. Lewis was engaged in the investigation of cases of duct overheating and underground cable failures caused by the proximity or failure of underground steam

F. A. LEWIS

mains. Then, as a member of the technical staff of the Bell Telephone Laboratories, Inc., (1930–31), Mr. Lewis was engaged in ferromagnetic research, particularly with respect to the determination of the magnetic properties and behavior of certain special alloys under different conditions and various heat treatments. Much of this work involved the development of ways and means of obtaining the required data. In January 1931, Mr. Lewis was engaged as a member of the Institute's publication staff, and during his 5 years of effective service has contributed in a major way to the development and expansion of the Institute's publication services through the medium of ELECTRICAL ENGINEERING. He is a member of Tau Beta Pi, and Pi Mu Epsilon, national honorary mathematical society.

J. C. PARKER (A'04, F'12, and past vice president) has resigned as president of the Brooklyn Edison Company, Inc., Brooklyn, N. Y., and has been elected a vice president of the Consolidated Gas Company, New York, a position in which he will have charge of all the activities relating to technical development, research, and experimentation for the entire group of electric, gas, and steam companies in the Consolidated system. Mr. Parker was born at Detroit, Mich., in 1879 and received the degrees of bachelor of science in mechanical engineering (1901), master of arts (1902), and electrical engineer (1904) from the University of Michigan. He was employed for a time by the General Electric Company, Schenectady, N. Y., and then became an instructor at Union College. In 1904 he became assistant to the engineer in charge of the Ontario Power Company, and the following year took a position with the Iroquois Construction Company, Buffalo, N. Y. From 1906 to 1915 he was mechanical and electrical engineer of the Rochester (N. Y.) Railway and Light Company, then for 7 years was professor in charge of the department of electrical engineering at the University of Michigan. Since 1922 he has been with the Brooklyn Edison Company as electrical engineer (1922–26), vice president in charge of engineering (1926–32), and president since 1932. He has served on many Institute committees, being active most recently on the committees on standards, legislation affecting the engineering profession, and Lamme Medal. Mr. Parker was a vice president of the Institute 1921–22. He is a member of the American Society of Civil Engineers and of The American Society of Mechanical Engineers.

D. W. MEAD (A'11, F'13) recently was elected president of the American Society of Civil Engineers at the 83d annual meeting of that society. Doctor Mead was born at Fulton, N. Y., March 6, 1862, and received the degree of civil engineer from Cornell University in 1884. During the period 1885–87 he was city engineer of Rockford, Ill., and engineer for the Rockford Water Power Company. He was occupied as a contractor from 1887 until he established a consutling engineering practice at Madison, Wis., in 1900. In 1904 the University of Wisconsin appointed him professor of hydraulic and sanitary engineering. He continued in his private practice, however, and was a member of the engineering board sent to China in 1914 by the American Red Cross and the Chinese Republic to study the problem of flood control on the Huai River. He was consulting engineer for the Miami Conservancy District (Ohio) during the planning and construction of the flood pro-

D. W. MEAD

tection works in 1915, a member of the committee that investigated the 1927 Mississippi floods for the National Chamber of Commerce, and a member of the Colorado River Board appointed under joint resolution of Congress to pass upon the plans for the Boulder Canyon project. He is now a member of the board that represents the federal government in connection with the Chicago Sanitary District's present construction work. The University of Wisconsin conferred upon him the honorary degree of doctor of laws at the time of his retirement in 1932. He is a member of the firm of Mead and Seastone, with offices at Madison, and the New York firm of Mead and Scheidenhelm. Doctor Mead is the author of several books on hydraulics. He is also a member of the American Institute of Consulting Engineers, The American Society of Mechanical Engineers, American Water Works Association, Tau Beta Pi, and Sigma Xi.

F. G. BOYCE (A'12, M'15) assistant manager of the production and transmission department of the Consumers Power Company, Jackson, Mich., for more than 18 years, has been appointed manager of that department. Mr. Boyce was born at Philadelphia, N. Y., February 8, 1884, and was graduated from the Bliss Electrical School in 1907. From 1909 to 1913 he was employed by the Allis-Chalmers Manufacturing Company, starting in the test course and becoming assistant to the head of the testing department. Later he was in charge of erection and field testing of both steam and electric installations as erecting engineer. In 1913 he accepted the position of substation construction foreman with Stone and Webster Engineering Corporation, Boston, Mass. Later in the same year he became electrical engineer for the Milwaukee (Wis.) Electric Railway and Light Company, and subsequently held a similar position with the Goodyear Rubber Company of Akron, Ohio. In 1917 he became assistant manager of the production and transmission department of the Consumers Power Company. Mr. Boyce is a member of The American Society of Mechanical Engineers.

W. B. HALL (A'21, M'28) former assistant professor of electrical engineering, Yale University, New Haven, Conn., has been appointed professor of electrical engineering and head of the department at Rhode Island State College, Kingston. Professor Hall is a native of Shelton, Conn., and was graduated from Yale University in 1916 with the degree of bachelor of philosophy in electrical engineering. Following a year of postgraduate study he entered the student course of the New York Telephone Company, but shortly entered the U.S. Naval Reserve to serve in various capacities. In 1919 he returned to the telephone company for a few months, then accepted the position of instructor in electrical engineering at Yale University. He was appointed assistant professor of electrical engineering in 1923. Professor Hall has also served as consultant for a number of industrial concerns. He was a member of the Institute's committee on general power applications 1924–25.

W. S. GOLL (A'17, M'27) manager of the Fort Wayne, Ind., works of the General Electric Company, has retired, although he will continue to work on special assignments. Mr. Goll is a native of St. Louis, Mo., and was graduated from Cornell Uni-

versity with the degree of mechanical engineer in 1896. The following year he entered the drafting department of the General Electric Company at Schenectady, N. Y., and a year later joined the Siemens-Halske Company, Chicago, Ill., which was taken over by the General Electric Company in 1901. In that year Mr. Goll became manager of the Fort Wayne Electric Works, and in 1909 accepted a similar position with the Northern Electrical Manufacturing Company at Madison, Wis. Both of these companies were later absorbed into the General Electric Company. In 1916 Mr. Goll was made assistant to the manager of the Fort Wayne works, and 2 years later became assistant manager. Since 1922 he had been manager.

W. R. MacDonald, Jr. (A'33) since 1934 a member of the Institute's publication staff, is now editorial assistant on Electrical Engineering. Mr. MacDonald is a 1932 electrical engineering graduate of Cornell University, Ithaca, N. Y., and is a second lieutenant, Signal Reserve Corps., U.S. Army, in which capacity he has served active tours of duty at Camp Dix., N. J., in 1932 and 1933 and at the Army maneuvers in upper New York State in 1935. Mr. MacDonald specialized in electronics and communication and, after graduation, built up a radio service and repair business which he carried on until he joined the Institute's staff. He was a member of the Institute's Student Branch at Cornell University, and is a member of Eta Kappa Nu.

Neil Currie, Jr. (A'12) manager of the Philadelphia, Pa., works of the General Electric Company for the past 6 years, has been made manager of the company's Fort Wayne, Ind., works. Mr. Currie was born at Currie, Minn., and received the degree of electrical engineer from the University of Minnesota in 1908. In that year he entered the power apparatus department of the Western Electric Company, and when this department was absorbed by the General Electric Company went to its Pittsfield, Mass., plant. In 1911 he became assistant engineer of the power motor engineering department, and in 1920 became engineer. Mr. Currie was appointed managing engineer of the Philadelphia works of the company in 1925, and manager in 1929.

R. E. Williams (A'35) has resigned as a member of the electrical engineering staff of Gibbs and Cox, Inc., marine and naval architects of New York, N. Y., to become a member of the Institute's publication staff where he will serve as editorial assistant on Electrical Engineering. Mr. Williams graduated from Purdue University, West Lafayette, Ind., in June 1934, with a degree of bachelor of science in electrical engineering. His practical experience includes summer and part-time work in the fields of aeronautics, public utilities, refrigeration, and radio, and, since graduation, in marine-electrical design. Mr. Williams was a member of the A.I.E.E. Student Branch at Purdue, and is an associate, Society of the Sigma Xi, national research honorary fraternity.

C. N. Gregory (A'25) who recently has been manager of the New Haven, Conn., office of the General Electric Company, has been appointed general manager of the United Illuminating Company, New Haven. Mr. Gregory was born at New York, N. Y., and received the degrees of bachelor of science in electrical engineering (1905) and electrical engineer (1906) from George Washington University. He had been with the General Electric Company since 1907, being employed in the testing, engineering, and commercial departments at Schenectady before taking the position of resident agent at Hartford, Conn., in 1913, a position which he held until he became manager at New Haven in 1928.

L. S. Harrison (A'19) since 1931 director of engineering for International Business Machines Corporation at Endicott, N. Y., has been appointed assistant to the president of that company with headquarters at New York, N. Y. He attended Polytechnic Institute of Brooklyn, and from 1912 to 1923 with the exception of a year in naval service was employed in the commercial division of the General Electric Company. In 1923 he became field engineer for the International Business Machines Corpoiation, and subsequently held various sales executive positions prior to his appointment as director of engineering in 1931.

F. W. Smith (A'05, M'12) president of the Consolidated Gas Company, New York Edison Company, and United Electric Light and Power Company, New York, N. Y., has been elected president of the Brooklyn Edison Company, Inc., to succeed J. C. Parker (A'04, F'12, and past vice president). Mr. Smith also was recently elected chairman of the board of the Electrical Association of New York, Inc. A biographical sketch of Mr. Smith was given on page 799 of Electrical Engineering for July 1935 in connection with his election as president of the Consolidated Gas Company.

F. A. Faron (A'21, M'27) since 1927 in charge of the transportation department in the New Haven, Conn., office of the General Electric Company, has been appointed manager of that office. Mr. Faron has been with the company since his graduation from Rhode Island State College in 1916, when he entered the testing department. Two years later he was assigned to special work in the d-c engineering department, and was associated with the railway engineering department from 1923 until his transfer to the New Haven office to be in charge of the transportation department.

H. H. Barnes, Jr. (A'00, F'13, and past vice president) commercial vice president, General Electric Company, New York, N. Y., has been elected president of the Electrical Association of New York, Inc. Mr. Barnes has served on many of the Institute's committees, and is now a member of the committees on code of principles of professional conduct, Edison Medal, Iwadare foundation, and Thomas Alva Edison foundation. He was a vice president of the Institute 1913–15.

J. A. Dewhurst (A'11) who has been with the McGraw-Hill Publishing Company, New York, N. Y., has joined the engineering staff of Ford, Bacon and Davis, Inc., New York. Mr. Dewhurst, who received the degree of bachelor of science in electrical engineering at the University of Washington in 1909, was connected with the McGraw-Hill Company for the past 10 years, his work including market analysis and sales. Among his previous business affiliations are the General Electric Company and the Twin City Rapid Transit Company.

E. F. McNaughton (A'32) since 1924 assistant engineer of the Railroad Commission of the State of California, San Francisco, has been appointed director of research of the commission. Mr. McNaughton was graduated from the University of California in 1922. During the last few years he has spent a considerable part of his time on special studies. In his new position Mr. McNaughton will have charge of the presentation of rate adjustment matters coming before the commission on behalf of the public.

G. A. Dyer (A'28) Southwestern Bell Telephone Company, recently was elected first vice president of the Dallas (Texas) Electric Club.

Obituary

Malcolm Churchill Rorty (A'03, M'26) president, American Management Association, New York, N. Y., died January 18, 1936. He was born at Paterson, N. J., May 1, 1875, and was a graduate of Cornell University, from which he received the degree of mechanical engineer in electrical engineering in 1896. For a short time he was engaged in construction work on the Niagara Falls transmission lines, then was wire chief and assistant district inspector with the New York Telephone Company (1897–99) and engineer and traffic engineer with the American Telephone and Telegraph Company (1899–1903). In 1903 he went to Pittsburgh, Pa., as general superintendent of traffic with the Central District Telephone Company, later becoming general superintendent and division manager, and in 1910 returned to New York to become commercial engineer with the American Telephone and Telegraph Company. Three years later he was made assistant vice president of the Western Union Telegraph Company, a position which he held for one year, after which he returned to the telephone company as special agent. In 1919, following his return from war service, Colonel Rorty became chief statistician of the American Telephone and Telegraph Company, and in 1922 was made assistant vice president after having been vice president of the Bell Telephone Securities Company 1921–22. Colonel Rorty became president of the International Telephone Securities Corporation and vice president of the International Telephone and Telegraph Company in 1923, holding the former posi-

tion until 1927 and the latter until 1930. In this work he was concerned with the securing of telephone concessions in many countries throughout the world. Colonel Rorty made various inventions in switchboard appliances and circuits, but was known mostly as a statistician and economist. He served as vice president of the American Founders Corporation 1930–31, and in 1934 became president of the American Management Association. Colonel Rorty was the author of a number of articles and books on economic subjects, and is said to have made original application of the theory of probability to telephone traffic problems. He was a fellow and past-president of the American Statistical Association, a member and past-president of the National Bureau of Economic Research, and a member of the Society for the Promotion of Engineering Education and Sigma Xi.

Jakob Emil Noeggerath (A'03, M'10, F'13) consulting engineer, New York, N. Y., died November 27, 1935, in Berlin, Germany. He was born at New York, October 3, 1877, and was educated in Germany, studying at the University of Charlottenburg (Berlin) and the University of Hanover, from which he received the degree of doctor of engineering in 1900. Doctor Noeggerath was employed at intervals from 1895 to 1900 in Ludwigshafen (Bavaria), Berlin, and Westphalia, and in 1901 entered the testing department of the General Electric Company at Schenectady, N. Y. In 1902 he was transferred to the a-c engineering department, and the following year was given charge of the work of development of acyclic (unipolar) apparatus. He was engaged in the electrical and mechanical design and the supervision of the manufacture, tests, and installations of these machines until 1910, and was the author of several technical papers describing them. Much of the original work and many inventions in connection with the development of the acyclic generator are credited to him. In 1910 Doctor Noeggerath opened offices as a consulting engineer in New York, working also in Zurich, Switzerland, and Munich, Germany. Following the World War Doctor Noeggerath undertook a study of electrolysis, working at first with a colleague but later alone. It had been found that the current necessary to decompose water is independent of the pressure under which the resulting gases are collected, and Doctor Noeggerath attempted to develop a process for practical use of this principle to avoid the need for compressors. The results of his study were given in a paper on high pressure electrolysis presented before the Berlin chapter of the Verein Deutscher Ingenieure in 1927.

Clifford Sherron MacCalla (A'01, M'10, F'13) vice president and division manager, Ohio Edison Company, Youngstown, died February 4, 1936. He was born at Wallingford, Pa., March 31, 1876, and was a graduate of the electrical engineering course at Lehigh University in the class of 1896. Following graduation he held various positions with the Philadelphia Bell Telephone Company, electric companies in Brooklyn, N. Y., and Pittsburgh, Pa., and the General Electric Company. In 1903 he accepted the position of assistant to general manager with The Washington Water Power Company, Spokane, designing and constructing several power generating stations. In this company he successively held the positions of assistant general manager, vice president and general manager, and chief engineer, leaving the company in 1918 to become works manager of the General Electric Company at Rochester, N. Y. Two years later he accepted the position of vice president and general manager with the Virginian Power Company at Charleston, W. Va., until 1923 he became president and general manager of the Pennsylvania Power Company and the Youngstown Municipal Railway Company, and vice president and general manager of the Pennsylvania-Ohio Power and Light Company. He had also held the office of president of the Ohio River Edison Company as well as being vice president and general manager of the Ohio Edison Company. Mr. MacCalla served on the power stations (now power generation) committee of the Institute 1914–16. He was a member of the American Society of Civil Engineers.

Harry Winthrop Turner (A'03 and member for life) winding and insulation specialist, research laboratory, General Electric Company, Schenectady, N. Y., died October 14, 1935. Mr. Turner was born at Chelsea, Mass., April 18, 1862. During 1882–83 he was employed by the Thomson-Houston Electric Company at New Britain, Conn., and until 1892 was with this company at Lynn, Mass., as armature winder, engaging also in experimental work. From 1892 to 1903 he was chief of the winding department of the Union Electricitaets Gesellschaft at Berlin, Germany, and then was connected with the British Thomson-Houston Electric Company at Rugby, England, as specialist on insulation and winding. Mr. Turner was then employed for similar work by the British Westinghouse Electric Company at Manchester until 1907, and from then until entering the employ of the General Electric Company at Schenectady in 1913 was engaged in consulting work and as a manufacturer's agent in London and Manchester.

Frank Land (A'91 and member for life) Nyack, N. Y., died December 24, 1935. He was born at San Francisco, Calif., June 25, 1868, and received his technical education at Cornell University, completing the electrical engineering course with the degree of mechanical engineer in 1891. For a short time he was employed by the General Electric Company and in installation work on the Syracuse (N. Y.) trolley system, then engaged in automobile parts manufacturing, and from 1903 to 1905 was employed by the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. The Land-Wharton Company was formed at Philadelphia, Pa., in 1905 with Mr. Land as incorporator and officer, and he participated in plans for extensions of the Remington Arms Company's plants at Bridgeport, Conn., and Ilion, N. Y. From 1913 to 1915 he was general manager of the Dyneto Electric Company, Syracuse, N. Y., manufacturing automotive electrical equipment, and then took charge of the planning and installation of electric power in the Ilion plant of the Remington Arms Company. Following this work he engaged in a consulting practice as a mechanical engineer, until in 1923 he became connected with the United Electric Light and Power Company, New York, N. Y., being so engaged until 1928.

Eugene H. Rosenquest (A'03) president, Westchester Lighting Company, Mount Vernon, N. Y., and Bronx Gas and Electric Company, New York, N. Y., died January 26, 1936. He was born at Tarrytown, N. Y., May 18, 1869. Mr. Rosenquest was for a time manager of the publishing house of Charles L. Webster and Company, and in 1893 accepted a position with the St. Louis River Water Power Company in Minnesota. In 1896 he became superintendent of the then newly formed Bronx Gas and Electric Company, and in 1898 was made vice president, a position which he held until he became president 3 years later. In 1926 he was elected president of the Westchester Lighting Company, and in 1932 was elected president of the Yonkers Electric Light and Power Company. Mr. Rosenquest, who served as a director of a number of utility companies, died the day before he was to have been elected a trustee of the Consolidated Gas Company, New York.

William John Melrose Davison (A'27) senior partner in the firm of Davison and Davidson, engineers and contractors in Mexico, F. D., Mexico, died November 17, 1935. He was born at Orizba, Mexico, June 15, 1890, and received the degree of bachelor of science from London University in 1908. He then entered the employ of the Mexican Light and Power Company, and later was employed by the Terreen Light, Power and Tramway Company and the Mexican Railroad. Just prior to 1914 he became construction engineer for a refinery of the Aguila Company, leaving to serve in the World War 1914–19. Mr. Davison returned again to this company and was in charge of electrical and construction work on the refinery at Tampico before he engaged in business as a manufacturers' agent and contractor.

Stuart Gunther Ellis (applicant for membership) radio engineer, Westinghouse Electric and Manufacturing Company, Chicopee Falls, Mass., died early in January 1936. Mr. Ellis was born at Denver, Colo., October 24, 1904, and received the degree of bachelor of science in electrical engineering at the University of Colorado in 1926. During the following year he was a student engineer with the Westinghouse Electric and Manufacturing Company at East Pittsburgh and Sharon, Pa., and since 1927 had been at Chicopee Falls as radio engineer. A paper by Mr. Ellis on the use of radio communication in railroading was published in Electrical Engineering for January 1936.

EDGAR PETER BROE (A'20) engineer Bell Telephone Laboratories, Inc., New York, N. Y., died December 19, 1935. He was born September 15, 1894 at New York, and received the degree of electrical engineer at Columbia University in 1917. Until he engaged in duty with the U.S. Naval Reserve in 1918, being responsible for the installation and operation of radio telephone and telegraph equipment in seaplanes at the Norfolk Navy Yards, Mr. Broe was in the engineering department of the American Telephone and Telegraph Company at New York. When he returned to the company in 1920 he became connected with the department of development and research, and until 1926 was concerned with local central office developments, then transferred to toll central office development. Following his transfer to the Bell Telephone Laboratories in 1934 Mr. Broe had been in the toll facilities department.

JAMES ROWLAND BIBBINS (A'02, M'14, F'20) consulting engineer, Washington, D. C., died January 27, 1936. Mr. Bibbins was born at Williamsport, Pa., May 25, 1877, and received the degree of bachelor of science in electrical engineering at the University of Michigan in 1899. He held several electrical and mechanical engineering positions during the following 9 years, and in 1909 joined the consulting firm of B. J. Arnold (A'92, F'12, member for life and past-president), Chicago, Ill. He was supervising engineer of that company from 1920 until he entered the employ of the United States Chamber of Commerce in 1922. In 1924 he established his own consulting engineering practice in Washington, D. C. He was a member of The American Society of Mechanical Engineers.

FRANCIS HENRY KNOX (A'94 and member for life) president, South Carolina Seacoast Railroad Company, died January 15, 1936. Mr. Knox was a native of Pittsburgh, Pa., and received his formal engineering training at the University of Pittsburgh. He assisted in the electrification of the Charleston (S. C.) street railway in 1897, and was engineer for the Seashore Railway. He was engaged in railway developments until he became general manager of the Spartanburg (S. C.) Railway, Gas, and Electric Company in 1907. He supervised the building of the Gaston Shoals hydroelectric plant in Cherokee County during his period of service with that company. In 1920 Mr. Knox became president of the Columbia (S. C.) Railway, Gas and Electric Company. He retired from active service in 1926.

PAUL FRANK RAUSCHER (A'29) field engineer for the Public Service Company of Northern Illinois, Waukegan, died December 21, 1935. Mr. Rauscher was born at Northome, Minn., June 1, 1906, and received the degree of bachelor of electrical engineering at the University of Minnesota in 1927. He was employed by the Commonwealth Edison Company, Chicago, prior to his association with the Public Service Company of Northern Illinois in 1928.

Membership

Recommended for Transfer

The board of examiners, at its meeting held February 19, 1936, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Everitt, W. L., prof. of E.E., Ohio State Univ., Columbus, Ohio.
Neild, J. F., E.E., Toronto Transportation Commission, Toronto, Ont.

To Grade of Member

Baxter, R. H., engr. in cost and depreciation work, Southwestern Bell Tel. Co., St. Louis, Mo.
Bernhardt, C. P., commercial engr., Westinghouse Elec. & Mfg. Co., New York.
Brown, L. P., elec. control and switchboard engr., Elliott Co., Ridgway, Pa.
Clapp, J. B., sales engr., James R. Kearney Corp., New York.
Cooper, F. A., engr., Southwestern Bell Tel. Co., St. Louis, Mo.
Coy, J. A., member technical staff, Bell Tel. Labs., Inc., New York.
Gallagher, J. E., process engr., Brooklyn Edison Co., Brooklyn, N. Y.
Harper, R. W., telephone engr., Bell Tel. Labs., Inc., New York.
Hartley, T. K., telephone engg., American Tel. & Tel. Co., New York.
Howard, C. G., manager, rectifier division, Fansteel Metallurgical Corp., No. Chicago, Ill.
Lindquist, K. E., engr. on foreign wire relations, N. Y. Telephone Co., Albany, N. Y.
McKee, E. R., head and prof. of E.E., Univ. o Vermont, Burlington, Vt.
Reich, H. L., mgr., elec. dept., Manila Machinery & Supply Co. Inc., Manila, Philippine Islands.
Wood, E. B., member of technical staff, Bell Tel. Labs., Inc., New York.

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1936, or May 31, 1936, if the applicant resides outside of the United States or Canada.

Abelson, M., Blackstone Valley Planning & Devpmt. Project, Worcester, Mass.
Ackerson, C., Gen. Elec. Co., Bloomfield, N. J.
Adams, J. J., 1122 S. 2nd Ave., Sioux Falls, S. D.
Allen, E. J., Gen. Elec. Co., Pittsfield, Mass.
Ambrose, P. J., Cadillac Motor Car Co., Detroit, Mich.
Anderson, J. H., Delco Products, Dayton, Ohio.
Andresen, A. J., 1694 Oxford St., Berkeley, Calif.
Aunger, R. E., Pub. Serv. Co. of No. Ill., Evanston.
Babbitt, J. K., Burgess Battery Co., Freeport, Ill.
Backer, C. M., 1514 Vine St., Scranton, Pa.
Baird, D. D., 1053—38th St., Des Moines, Iowa.
Baker, M. C., Brooklyn Edison Co. Inc., New York.
Baker, R. B., Jr., Florida Pwr. Corp., St. Petersburg.
Barlow, H. P., Associated Tel. Co. Ltd., Long Beach, Calif.
Barnett, R. M., Youngstown Sheet & Tube Co., Indiana Harbor, Ind.
Barre, M. L., Southern Bell Tel. & Tel. Co., Jacksonville, Fla.
Beachley, R. W., Bethlehem Steel Corp., Sparrows Point, Md.
Bechtol, P. S., B. F. Goodrich Co., Akron, Ohio.
Beethem, R. B., Collins Radio Co., Cedar Rapids, Iowa.
Beers, C. A., Gen. Elec. Co., Erie, Pa.
Beggs, P. B., Mills Memorial Hospital, San Mateo, Calif.
Beistline, W. E., Mountain States Tel. & Tel. Co., Albuquerque, N. M.
Benser, W. M., Consolidated Gas Elec. Lt. & Pwr. Co., Baltimore, Md.
Berkowitz, H., Flynn Hill Elevator Co., New York, N. Y.
Bessey, G. S., Brand Co., Boston, Mass.
Biele, R. J., Gen. Elec. Co., Bridgeport, Conn.
Bird, M. R., Gen. Elec. Co., Bloomfield, N. J.
Bishop, H. W., 4120—5th St., N. W., Washington, D. C.
Blakely, R. T. C., Intl. Business Machines, New York, N. Y.
Bloom, S. L., 2112 N. 10th St., Milwaukee, Wis.
Bodman, R. E., Gen. Elec. Co., Pittsfield, Mass.
Bouquin, H. F., 1049 W. Second St., Oil City, Pa.
Bowden, H. W., Eastman Kodak Co., Rochester, N. Y.
Bowman, J. W., Indiana & Michigan Elec. Co., South Bend.
Bowman, N., Detroit Edison Co., Mt. Clemens, Mich.
Bozzuffi, E. M., CCC, Aberdeen Proving Ground, Maryland.
Brazauski, B. J., Standard Forgings Co., Indiana Harbor, Ind.
Bright, F. W., Central Hanover Bank & Trust Co., New York, N. Y.
Broderson, H., Montana Dakota Pwr. Co., Glendive.
Brown, C. W., Staley Mfg. Corp., Columbus, Ind.
Brown, G. N., 932 W. Midwest Ave., Casper, Wyo.
Brown, J. L., Gen. Elec. Co., Erie, Pa.
Brown, L. M., Michigan Bell Tel. Co., Detroit.
Brown, W. J., c/o D. L. Miller, Inc., Hillside, N. J.
Brownell, B. B., Delco Products Corp., Dayton, Ohio.
Bruton, J. F., Dist. of Columbia, Highway Dept., Washington, D. C.
Buehl, R. C., Mass. Inst. of Tech., Cambridge.
Buzzee, M. H., Jr., Colonial Beacon Oil Co., Brookline, Mass.
Cahalan, E. T., F. W. Sickles Co., Springfield, Mass.
Cameron, E. G., Pacific Can Co., San Francisco, Calif.
Campani, J., New York Edison Co., Inc., N. Y.
Carey, F. L., 1807 N. 51st St., Seattle, Wash.
Carlson, E. L., Gen. Elec. Co., New York, N. Y.
Carlson, O. V., Linde Air Products Co., Newark, N. J.
Claggett, T. J. C., Cons. Gas & Elec. Co. of Baltimore, Md.
Clark, J. R., Gen. Elec. Co., Schenectady, N. Y.
Clements, C. C., Am. Television Inst., Benton, Ala.
Clothier, G. W., Univ. of Washington, Seattle.
Clotworthy, C. B., Jr., Bethlehem Steel Co., Lackawanna, N. Y.
Coddington, R. W., 5012—22nd N. E., Seattle, Wash.
Coddington, W. H., Gen. Elec. Co., Springfield, Ill.
Cohen, J., 954 R St., N. W., Washington, D. C.
Corbet, W. W., Jr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Corker, B. B., U.S. Engg. Dept., Hinton, W. Va.
Coss, B. A., Ohio Pwr. Co., Newark, Ohio.
Costello, J. J. (Member), 201 Devonshire St., Boston, Mass.
Cripe, D. W., A-C Spark Plug Co., Flint, Mich.
Crosby, D. R., Federal Telegraph Co., Newark, N. J.
Crossley, C. B., Hammond & Little River Redwood Co., Ltd., Samoa, Calif.
Cunningham, J. C., Jr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Curren, G. W., Lawrence Gas & Elec. Co., Mass.
Cutlip, S. B., John E. Fast & Co., Chicago, Ill.
Davidge, R. C., Gen. Elec. Co., Schenectady, N. Y.
Delmonte, J., Naval Aircraft Factory, U.S. Navy Yard, Philadelphia, Pa.
Dempsey, W. A., 43 Hadwen Rd., Worcester, Mass.
Denison, H. G., Gulf States Utilities Co., Iowa, La.
Denkhaus, W. F., Bell Tel. Co. of Pa., Philadelphia.
Dey, N. A., Dominion Cutout Co., Ltd., Toronto, Can.
Di Addario, T., 511 Northland Ave., Buffalo, N. Y.
Douglass, W. P., Procter & Gamble Co., Ivorydale, Ohio.
Dowler, E. A., Weirton Steel Co., Hollidays Cove, W. Va.
Dungan, W. E., Jr., Gen. Elec. Co., Schenectady, N. Y.
Drake, E. P., Cross Abbott Co., White River Junction, Vt.
Dylewski, L. J., Florida Pwr. & Lt. Co., Sarasota.
Eastman, D. P., Trumbull Elec. Mfg. Co., Seattle, Wash.
Eaton, J. B., Jr., Gulf Refining Co., New Orleans, La.
Ebel, L. C., Anaconda Wire & Cable Co., Hastings-on-Hudson, N. Y.
Elfers, P. L., U.S. Engg. Dept., Fort Peck, Mont.
Ellis, H. K., Jr., Intl. Business Machines Corp., New York, N. Y.
Elmore, H. C., Box 243, Chelan, Wash.
Elston, W. T., Jr., Central Hudson Gas & Elec. Corp., Kingston, N. Y.
Engelfried, G. C., New York Central R.R., Syracuse, N. Y.
Emerson, L. P., Foxboro Co., No. Attleboro, Mass.
Epstein, A. M., D'Elia Elec. Co., Bridgeport, Conn.
Erven, J. W., Bureau of Pwr. & Lt., Los Angeles, Calif.
Evans, L. W., Box 63, Wells, Nev.
Evans, R. L., R. R. 1, Sabetha, Kan.
Fahey, J. D., 1732 Carleton St., Berkeley, Calif.
Fargo, R. W., N. Y., N. H., & H. R. R. Co., Chester, Conn.
Fetcher, J. R., E. G. Budd Mfg. Co., Philadelphia, Pa.
Finley, J. T., J. R. Kearney Corp., St. Louis, Mo.
Fisher, E. A., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.

Fortenbaugh, C., Gen. Elec. Co., Cincinnati, Ohio.
Fortino, E. P., Philco Radio & Television Corp., Philadelphia, Pa.
Friedland, N., Belmet Products Inc., Brooklyn, N. Y.
Gaffney, F. J., B. F. Sturtevant Co., Hyde Park, Mass.
Gamble, G. P. (Member), Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Ganoung, R. E., Procter & Gamble Co., Memphis, Tenn.
Gartelmann, L. H., Interborough Rapid Transit Co., New York, N. Y.
Gateka, F. F., Southwestern Lt. & Pwr. Co., Chickasha, Okla.
Geisler, H. P., Jr. (Member), Stone & Webster Engg. Corp., Boston, Mass.
Gillon, V. C., Oklahoma Gas & Elec. Co., Oklahoma City.
Gilsdorf, W. R., Nat. Theatre Supply Co., Cleveland, Ohio.
Giolma, F. V., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Gleason, C. L., Coast Counties Gas & Elec. Co., Santa Cruz, Calif.
Gluckman, H. P., Bureau of Pwr. & Lt., San Pedro, Calif.
Goehringer, E. E., Lincoln Elec. Co., Cleveland, Ohio.
Goetz, M. D., New York Edison Co., Inc., N. Y.
Goldfarb, M. N., Pub. Serv. Comm., Charleston, W. Va.
Gould, P., New York Telephone Co., N. Y.
Goumeniouk, G. I., 3981 West 23rd Ave., Vancouver, B. C., Canada.
Gravitt, V. V., Gen. Elec. Co., Schenectady, N. Y.
Greenwood, G. D., Norton Co., Worcester, Mass.
Greer, R. J., U.S. Engg. Dept., Cape Cod Canal, Buzzards Bay, Mass.
Greisser, J. R., 444 Tennyson Ave., Palo Alto, Calif.
Gruters, B. E., New York Tel. Co., N. Y.
Guerdan, D. A., City of Paris Dry Goods Co., San Francisco, Calif.
Haas, E. J., Jr., Celotex Corp., Marrero, La.
Haberstroh, A., Buckley & Scott Utilities Inc., Boston, Mass.
Hackett, V., Gen. Elec. Co., Schenectady, N. Y.
Hadden, G. R., New York Edison Co., Inc., N. Y.
Hagius, K. S., The Texas Co., Houston.
Hale, E. E. (Member), Pub. Serv. Comm. of New York, N. Y.
Hall, H. B., 75 Lincoln Ave., Amsterdam, N. Y.
Hallaway, A. B., Minneapolis Gen. Elec. Co., Minn.
Hamerly, L. R., 2703 E. 54th St., Seattle, Wash.
Hammond, W. W., Montgomery Brothers, San Francisco, Calif.
Haneiko, J. G., Pilgrim State Hospital, Jericho, L. I., N. Y.
Hanson, E. B., Franklin Heating Sta., Rochester, Minn.
Hanson, R., Champion Radio Works, Danvers, Mass.
Harkness, B. R., RCA Victor Mfg. Co., Inc., Camden, N. J.
Harries, W. H., U.S. Bureau of Reclamation, Coulee Dam, Wash.
Hart, R. C., U.S. Forest Serv., Quilcene, Wash.
Hastings, C. E., Nat. Advisory Comm. for Aeronautics, Langley Field, Va.
Hastings, G. M., Nat. Broadcasting Co., Inc., New York, N. Y.
Hayes, W. S., Pub. Serv. Elec., Hackensack, N. J.
Hays, R. F., Jr., Mississippi State Coll., State College.
Hebel, W. M., Waterbury Tool Co., Conn.
Heil, V. E., P. R. Mallory Co., Indianapolis, Ind.
Herman, F. A., Jr., c/o W. Herman, New Rochelle, N. Y.
Hitt, J. C., U.S. Naval Reserve, Pensacola, Fla.
Hobrecht, J. P., Otis Elevator Co., San Francisco, Calif.
Hoffman, E. DeC., Westinghouse Elec. & Mfg., Co., Newark, N. J.
Holcomb, C. E., Brooklyn Edison Co., New York.
Holt, F. H., Gen. Elec. Co., Schenectady, N. Y.
Holtom, H. T., Metropolitan Water Dist. of So. Calif., Arlington.
Hoover, D. B., Landis Tool Co., Waynesboro, Pa.
Hope, C. R., Leland Elec. Co., Dayton, Ohio.
Hopper, A. L., Navy Yard, New York, N. Y.
Howell, A. W., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Hower, E. F., Colorado State Highway Dept., Trinidad.
Howze, W. D., 422 Alpine St., Los Angeles, Calif.
Huckaby, F. F., Southwestern Lt. & Pwr. Co., Lawton, Okla.
Hulbert, F. L., Cadillac Motor Car Co., Detroit, Mich.
Hurson, F. J., Div. of Materials, Washington, D. C.
Jackson, H. H., Jr., Detroit Edison Co., Mich.
Jaffe, D. L., Coll. of City of New York, N. Y.
Jaros, O. J., U. S. Vanadium Corp., Naturita, Colo.
Johnson, E. F. (Member), Florida Pwr. & Lt. Co., Miami.
Johnson, W. L., 8017 S. E. Carlton St., Portland, Ore.
Johnston, P. M., Soil Conservation Serv., Meridian, Miss.
Jones, R. P., Standard Gasoline Co. of Calif., Santa Fe Springs.
Jones, W. G., 805 E. Fourth St., Tucson, Ariz.
Jordan, J. F., Baldwin Piano Co., Cincinnati, Ohio.
Josberger, F. G., L. I. Ltg. Co., Roslyn Heights, N. Y.
Kapell, S. M., Brooklyn Edison Co., New York.
Katcher, A. A., Columbia Univ., New York, N. Y.
Kells, D. G. (Member), New York Edison Co., Inc., N. Y.
Kennedy, H., Cutler-Hammer Corp., Milwaukee, Wis.
Kennedy, R. M., Metropolitan Edison Co., Topton, Pa.
Kesti, A. A., Bulldog Elec. Products Co., Detroit, Mich.
Kidd, R. E., Gen. Elec. Co., Schenectady, N. Y.
Kidder, L. Z. (Fellow), Securities & Exchange Comm., Washington, D. C.
Kieffer, R. C., Metropolitan Edison Co., Reading, Pa.
Kirkish, J. J., 2981 So. Wentworth Ave., Milwaukee, Wis.
Kitchen, E. T., Graystone Hotel, Beulah, N. D.
Kleabonas, A. B., New York Pwr. & Lt. Corp., Schenectady.
Kleinert, P. F., Jr., Am. Tel. & Tel. Co., New York, N. Y.
Kovac, D. R., Gilbert Knitting Co., Little Falls, N. Y.
Krefft, H. H., Standard Transformer Corp., Chicago, Ill.
Kruempel, C. K., A. C. Smith Corp., Milwaukee, Wis.
Ladd, G. O., Pub. Serv. Co. of Okla., Tulsa.
Lamberton, A. F., Taylor Instrument Co., Rochester, N. Y.
Lange, P. F., Nat. Petroleum Pub. Co., Cleveland, Ohio.
Lans, A. W., Chapman St., No. Walpole, Mass.
Lauchland, L. S., Electro Metallurgical Co. of Canada, Ltd., Welland, Ont., Can.
Lawson, N. J., Interstate Dispatch Inc., Milwaukee, Wis.
Layman, C. A., Layman Radio Serv., Akron, Ohio.
Leach, F. C., Elec. Products Corp., Los Angeles, Calif.
Lehde, H. C., Arma Engg. Co., Brooklyn, N. Y.
Lehman, W. E., Bell Tel. Co. of Canada, Toronto, Ont.
Lehning, T. C., 32–74—33rd St., Astoria, L. I., N. Y.
Leitner, F. J., Philip Carey Co., Lockland, Ohio.
Lerner, G. P., Noblitt-Sparks Ind. Inc., Columbus Ind.
Leuthold, E. J., Tung-Sol Lamp Wks., Inc., Newark, N. J.
Lewis, H. S., Central Vt. Pub. Serv., Corp., Rutland.
Lewis, J. R., Maryland Coal Co. of Pa., St. Michael, Pa.
Lewis, L. J., Pub. Serv. Corp., Coalinga, Calif.
Lewis, M. G., U.S. Navy, Pub. Wks. Drafting Dept., Mare Island, Calif.
Lieske, E. W., Newhall, Iowa.
Light, P. H., Gen. Elec. Co., Pittsfield, Mass.
Lind, W. J., Univ. of British Columbia, Vancouver, B. C., Can.
Link, G. H., Jr., Ohio Pwr. Co., Coshocton, Ohio.
Locher, H. H., Consumers Pwr. Co., Jackson, Mich.
Long, L. J. W., Agfa Ansco Corp., Binghamton, N. Y.
Lowy, P. M., Gen. Elec. Co., Schenectady, N. Y.
MacKinney, J. J., E. G. Budd Mfg. Co., Philadelphia, Pa.
MacSorley, O. L., RCA Victor Co., Camden, N. J.
Madden, R. H., 161–23—84th Rd., Jamaica, N. Y.
Madsen, L. D., 1515 Leavenworth, Manhattan, Kan.
Mair, A. D., Mackay Radio & Tel. Co., Los Angeles, Calif.
Majors, H., Jr., 1625 Grant St., Concord, Calif.
Manning, J. V., Baldor Elec. Co., St. Louis, Mo.
Manning, M. L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Mather, G. H., Elec. Boat Co., Groton, Conn.
Mathews, J. A., Jr., Hammond Clock Co., New York, N. Y.
Matthews, R. W., Groveton, N. H.
Maust, C. I., Pub. Serv. Elec. & Gas Co., Newark, N. J.
Maxwell, E., 68 East 35th St., Brooklyn, N. Y.
Mayer, I. S., 1824 Pendleton St., Columbia, S. C.
Mazzola, J. R., Micamold Radio Corp., Brooklyn, N. Y.
McCullar, W. A., Oklahoma Gas & Elec. Co., Enid.
McDonough, M. E., 233 Naval Air Station, Pensacola, Fla.
McKinster, J. E., Indiana Bell Tel. Co., Indianapolis.
McMillan, W. R., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
McMullen, W. F., Univ. of Toronto, Toronto, Ont., Can.
McNaughton, R. N., Hotel Hershey Arms, Los Angeles, Calif.
McWhorter, W. A., Jr., 1142 West Mississippi Ave., Denver, Colo.
Mecklenburg, L. W., Jr., Janette Mfg. Co., Chicago, Ill.
Merker, H. M., Aluminum Co. of Am., Massena, N. Y.
Miller, R. B., Iowa City Lt. & Pwr. Co., Iowa.
Misenhimer, R. H., Southern Sierras Pwr. Co., El Centro, Calif.
Mitchell, R. L., Philco Radio & Television Corp., Philadelphia, Pa.
Mobley, M. C., Jr., D. & N. Auto Parts Co., Cleveland, Miss.
Modisette, M. H., Shell Petroleum Corp., Jennings, La.
Mohaupt, E. E., 3607 W. Galena St., Milwaukee, Wis.
Molthman, M., Elec. Motors Corp., New York, N. Y.
Monkhouse, J. R., Petty Geophysical Engg. Co., Eunice, N. M.
Montmeat, F. E., Jr., 492 E. 29th St., Paterson, N. J.
Moore, J., West Falmouth, Mass.
Morrison, J. F., Bell Tel. Co., St. Louis, Mo.
Mortensen, M. A., Jr., Gen. Elec. Co., E. Cleveland, Ohio.
Mueller, C. W., Raytheon Production Corp., Newton, Mass.
Murphy, R. W., Commercial Tire Co., Seattle, Wash.
Murray, C. H., Georgia Pwr. Co., Atlanta.
Myers, W. H., Metropolitan Water Dist. of So. Calif., Banning, Calif.
Myszewski, F. T., A. O. Smith Corp., Milwaukee, Wis.
Nacinovich, T. P., Western Elec. Co., Inc., Kearny N. J.
Neidorf, S. W., Tungsol Lamp Wks., Newark, N. J.
Newcomb, H. M., Hudson Co., E. Jefferson, Mich.
Newman, J. J., Gates Rubber Co., Denver, Colo.
Nichols, W. A., Corning Glass Works, N. Y.
Nopper, W. L., Allis-Chalmers Mfg. Co., West Allis, Wis.
Novak, T. S., 2025 E. Pratt St., Baltimore, Md.
O'Brien, E. D., Watts Pharmacy, Pullman, Wash.
O'Halloran, T. A., Chesapeake & Potomac Tel. Co., Washington, D. C.
Oldenkamp, H. A., Lincoln Elec. Co., Cleveland, Ohio.
Otterbourg, M. A., Southern Ry. System, Charlotte, N. C.
Otzmann, H., Jr., Westinghouse Elec. & Mfg., Co., Newark, N. J.
Packer, E. F., Jr., Elec. Serv. Supplies Co., Philadelphia, Pa.
Pagella, C., Brooklyn Edison Co., New York.
Parcinski, Henry J., School of Industrial Arts, Trenton, N. J.
Parker, W. A., Oklahoma Gas & Elec. Co., Oklahoma City.
Pehousek, F., Los Angeles Gas & Elec. Corp., Calif.
Perkins, K. H., Talon Hookless Fastener Co., Erie, Pa.
Perry, H. I., Gen. Elec. Co., New York, N. Y.
Perry, N., Army Air Corps., Randolph Field, Texas.
Peters, A. L., Jr., 3342 Pensacola Ave., Chicago, Ill.
Peterson, C., c/o H. A. Wilson Co., Newark, N. J.
Peterson, T. W., N. W. Bell Tel. Co., Fargo, N. D.
Petzinger, A. J., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Pohl, G. O., Commonwealth Edison Co., Chicago, Ill.
Platteter, A. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Pomykata, J. M., New River Coal Co., Mt. Hope, W. Va.
Pratt, J. A., Canadian Westinghouse Co. Ltd., Hamilton, Ont., Can.
Prescott, H. L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Priebe, H. W., Detroit Edison Co., Mt. Clemens, Mich.
Pugsley, D. W., Gen. Elec. Co., Bridgeport, Conn.
Rader, V. P., Am. Gas & Elec. Co., New York, N. Y.
Rardon, N. C., Fairbanks, Morse & Co., St. Louis, Mo.
Reid, T. H., 6053—30th Ave., N. E., Seattle, Wash.
Renoff, P. V., 211 N. Calvert St., Baltimore, Md.
Reynolds, R. C., Doehler Die Casting Co., Toledo, Ohio.
Reynolds, T. W., 326 High St., Passaic, N. J.
Riggs, J. H., Rudolph Wurlitzer Co., N. Tonawanda, N. Y.
Ritter, F. T., Roller-Smith Co., Bethlehem, Pa.
Rodgers, L. M., Gen. Elec. Co., Bridgeport, Conn.
Roebuck, M. E., 310 E. Capitol St., Washington, D. C.
Rogers, T. I., Am. Tel. & Tel. Co., New York, N. Y.
Rogers, W. A., Newport News Shipbuilding & Dry Dock Co., Va.
Roller, L. H., Carrier Engg. Corp., Newark, N. J.
Rose, R. R., Hermon, N. Y.
Rosencrans, C. Z. (Member), Leeds & Northrup Co., Philadelphia, Pa.
Rosenhein, E., 1840 Phelan Place, New York, N. Y.
Ross, B. M., Cincinnati & Suburban Bell Tel. Co., Ohio.
Ross, G. L., 12724 Bartfield Ave., Cleveland, Ohio.
Rosso, F. P., Cherokee Municipal Plant, Okla.
Rothganger, F., Pacific Gas & Elec. Co., Emeryville, Calif.
Royalty, M., Southwestern Associated Tel. Co., Lubbock, Texas.
Rule, B. H., Dept. Lt. & Pwr., Vernon, Calif.
Russell, F. A., Arcturus Radio Tube Co., Inc., Newark, N. J.
Rystedt, T., Western Union Tel. Co., New York, N. Y.
Salamon, M. A., Gen. Elec. Co., New York, N. Y.
Santo, R. E., Univ. of Toronto, Ont., Can.
Sasser, W. L., U.S. Engrs. Dept., Booneville, Ore.
Sawyer, F. B., Southwestern Bell Tel. Co., Webster Groves, Mo.
Schaefer, L. P., Square D Co., Detroit, Mich.
Schlegel, R. A., Philadelphia & Reading Coal & Iron, Mahanoy City, Pa.
Schwarz, D. W., Intl. Business Machines, Harrisburg, Pa.
Scott, R. S., Buick Motor Co., Flint, Mich.
Scutt, J. M., Ford Instrument Co., Long Island City, N. Y.
Seddon, R. E., Bethlehem Steel Co., Lackawanna, N. Y.
Sharbrough, H. M., Murley-Rolleston Corp., New York, N. Y.
Sheatsley, P. W. (Member), Bell Tel. Lab., New York, N. Y.
Shepherd, R. V., Gen. Elec. Co., Schenectady, N. Y.
Shimp, R. P., Philco Radio & Tel. Corp., Philadelphia, Pa.

Sickles, G., Jr., 59 Ingraham Place, Newark, N. J.
Sickles, R. W., DeLaval Steam Turbine Co., Trenton, N. J.
Siegel, S. S., Made-Rite Appliance Mfg. Corp., Cleveland, Ohio.
Sipp, E. F., Jr., 25 Gladys Ave., Hempstead, L. I., N. Y.
Skina, A. G., Bunker Hill Sullivan Co., Kellogg, Idaho.
Skrobisch, A., Columbia Univ., New York, N. Y.
Slamovitz, M. I., 91 Broadway, Paterson, N. J.
Smith, G. A., Southwestern Lt. & Pwr. Co., Lawton, Okla.
Smith, J. W., Gen. Elec. Co., Schenectady, N. Y.
Smith, T. C., Edison Gen. Elec. Appliance Co., Chicago, Ill.
Snyder, J. G., E. I. duPont de Nemours & Co., Deepwater, N. J.
Snyder, R. W., Gen. Elec. Co., Schenectady, N. Y.
Sotirov, B., 39 W. 60th St., New York, N. Y.
Sottile, F. J., New York Edison Co., Inc., N. Y.
Squires, H. W. (Member), John A. Roebling's Sons Co. of Calif., San Francisco.
Stinson, L. J., Bureau of Pwr. & Lt., Los Angeles, Calif.
Stockheimer, E. J., New York Edison Co., Inc., N. Y.
Stone, B. L., Western R.R. Supply Co., Chicago, Ill.
Streifus, C. A., Idaho State Planning Board, Boise.
Stringfield, T. W., New York Edison Co., Inc., N. Y.
Sunkel, R. F., United States Rubber Products, Inc., St. Louis, Mo.
Sursaw, C. A., Buick Motor Car Co., Flint, Mich.
Sussman, H. W., Elec. Generator & Motor Co., Cleveland, Ohio.
Sutherland, A. M., Central Ill. Lt. Co., Peoria.
Talberth, H., Am. Tel. & Tel. Co., New York, N. Y.
Tatum, F. W., Am. Dist. Tel. Co. Inc., New York, N. Y.
Taylor, C. C. (Member), Bell Tel. Lab., New York, N. Y.
Taylor, F. A., Lane Wells Co., Los Angeles, Calif.
Taylor, W. H., U.S. Bureau of Reclamation, Denver, Colo.
Ten Broeke, E. F., Western Elec. Co., Kearny, N. J.
Thomas, R. H. Co., 2846, Camp S. C. S. 18N, Buckhorn, New Mexico.
Thompson, W. E., Southern States Equipment Co., Birmingham, Ala.
Tinkler, G. F., Cereal Prod. Ref. Corp., San Francisco, Calif.
Trask, L. M., Southern New Eng. Tel. Co., New Haven, Conn.
Trovinger, R. E., Robbins & Myers Inc., Springfield, Ohio.
Tucker, W. M., 1260 Talbert St., S. E., Washington, D. C.
Uradnisheck, J., Boeing Aircraft Co., Seattle, Wash.
Uzunaris, W. M., Wisconsin Steel Co., Chicago, Ill.
Valentine, B. I., Idaho Pwr. Co., Boise.
Van Court, L. P., P. R. Mallory Inc., Indianapolis, Ind.
Van Vessem, G. E., Western Elec. Co., West Haven, Conn.
Vaughn, E. L., Heald Machine Co., Worcester, Mass.
Vlach, W. H., 1501 Madison St., Oakland, Calif.
Volland, G., N. Y. & Q. Elec. Lt. & Pwr. Co., Flushing, N. Y.
Von Dohlen, H. W., Jr., Radio Station WRUF, Gainesville, Fla.
Waldo, N. E., Am. Dist. Tel. Co., New York, N. Y.
Walker, O. N., Gen. Elec. Co., Bridgeport, Conn.
Wallace, W. H., Fulton Lt., Heat & Pwr. Co., New York.
Walsh, R. L. (Member), Universal Atlas Cement Co., Chicago, Ill.
Walsh, W. T., 460 Fell St., Apt. 5, San Francisco, Calif.
Warren, H. A., Florida Mapping Project, Gainesville.
Watmough, A. L., Gen. Elec. Co., Schenectady, N. Y.
Weaver, A. R., Graybar Elec. Co., Toledo, Ohio.
Webber, F. G., c/o F. W. Sickles Co., Springfield, Mass.
Weiss, F. P., Wilkes-Barre Township Jr. & Sr. High Sch., Wilkes-Barre, Pa.
Weiss, N. S., 717 Weiser St., Reading, Pa.
Westerlund, H., Gen. Motors Truck Corp., Pontiac, Mich.
Wetmore, W. F., Detroit Edison Co., Mich.
Whitaker, P. W., Carter Oil Co., Seminole, Okla.
White, R. F., King Soloman Mines, Black Bear, Calif.
Whitney, E. C., Westinghouse Elec. & Mfg. Co., Detroit, Mich.
Wilde, A. J., Federal Govt., Washington, D. C.
Williams, D. J., W. Montelius Price Co., Seattle, Wash.
Wilmeth, T. S., Allis-Chalmers Mfg. Co., West Allis, Wis.
Winfree, W. C., Jr., Station WJAX, Jacksonville, Fla.
Winser, L., Mackey Radio & Tel. Co., Kaweah, Tulare Co., Calif.
Wolf, A. M., Cutler Hammer Inc., Milwaukee, Wis.
Woodall, T. H., Central Agency, Fort Defiance, Ariz.
Young, K. A., 707 W. 7th St., Concordia, Kan.
York, L. H., Bureau of Pwr. & Lt., Los Angeles, Calif.
Young, C., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Zaslavsky, S., 1155 St. John's Place, Brooklyn, N. Y.
Zbell, S. P., 135 Hall of Fame Terrace, New York, N. Y.
Zochert, D. P., Pub. Serv. Co. of No. Ill., Maywood.
Zoebel, L. E., Kalunite Co., Salt Lake City, Utah.

401 Domestic

Foreign

Atherton, J. B., Ewa Plantation Co., Hawaii.
Bentley, N. H., British Permel Enamelled Wire Ltd., Charlton, London, S. E. 7, Eng.
Collazo, H., Box 108, Rio Piedras, P. R.
Hacker, G., Kabelfabrik und Drahtindustrie Actien-Gesellschaft, Vienna, Austria.
Kubo, T., Hitachi Engg. Wks., Sukegawa, Ibaraki-ken, Japan.
Lebacqz, J. V., 34 Avenue de la Cascada, Brussels, Belgium.
Marti, H., P. O. Box 26, Mayaguez, P. R.
Mascott, L. L., P. O. Box 2568, Mexico, D. F., Mexico.
Mehta, N. S. (Member), Rohit Mills, Ahmedabad, India.
Miyagi, K., Sumitomo Elec. Wire & Cable Wks. Ltd., Konohana-ku, Osaka, Japan.
Molina, R. L., Mayaguez Lt. Pwr. & Ice Co., Porto Rico.
Rudt, E., Apartado 83, Tetuan, Morocco, French West Africa.
Sanchez, R., Mayaguez Lt., Pwr. & Ice Co., San German, Porto Rico.
Sawhney, B., Shanan Power House, Joginder, Nagar, N. India.
Strachan, C. A., Council Chambers, Fairfield, N. S. Wales, Australia.
Truscott, D. N., Murphy Radio Co., Welwyn Garden City, Herts, Eng.

16 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Beaumont, L., Box 404, Shanghai, China.
Blanc, Victor, 153 Boulevard Lefebvre, Paris, France.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Huang, Pienchun, Schillerstr 57, Berlin, Germany.
Kummer, Emil F., Box 898, Bridgeport, Conn.
Murray, Forrest H., 5530 Dorchester Ave., Chicago, Ill.
Patel, Ishvarlal B., 5 Second Carpenters St., Bombay, 4, India.
Soskin, Samuel B., 1141 S. Central Park, Chicago, Ill.
Spiegel, William F., 7 Stegman Court, Jersey City N. J.

9 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

OUTPOSTS of SCIENCE. By B. Jaffe. N. Y., Simon and Schuster, 1935. 547 p., illus., 10x6 in., cloth, $3.75. An account of modern achievements in some important fields of physics and biology.

HIGH SPEED DIESEL ENGINES with Special Reference to Automobile and Aircraft Types. By A. W. Judge. 2 ed. N. Y., D. Van Nostrand Co., 1935. 347 p., illus., 9x6 in., cloth, $6.00. Theoretical and practical aspects of the engine are presented in this volume, which is intended as an elementary text for engineers and students.

MERCURY-ARC CURRENT CONVERTORS, an Introduction to the Theory of Vapour-Arc Discharge Devices and to the Study of Rectification Phenomena. By H. Rissik, with a foreword by J. M. Donaldson. N. Y., Pitman Pub. Corp.; Lond., Sir Isaac Pitman & Sons, Ltd., 1935. 424 p., illus., cloth, $6.00. Presents rectifier theory in an elementary manner, requiring only ordinary mathematical equipment, and devotes a section to current conversion, including the principles of grid control, invertors and cycloconvertors, the generation of harmonics, and the calculation of rectifier circuit data.

NEL CINQUANTENARIO DELLA SOCIETÀ EDISON, 1884–1934. (On the Fiftieth Anniversary of Società Edison.) By various authors. Milan, Società Edison, 1934. 4 vols.; v. 1, 510 p.; v. 2, 487 p., v. 3, 632 p., v. 4, 318 p., illus., cloth, apply. A review of the evolution of electric power during the lifetime of the oldest electric public utility of Europe. The first volume describes developments, the second and third volumes discuss the general economic problems of the industry, and the final volume describes the economic development of Milan and contains a history of the Società Edison.

STORY of INDEPENDENT TELEPHONY. By H. B. MacNeal. Chicago, Independent Pioneer Telephone Assoc., 1934. 289 p., tables, 9x6 in., cloth, $3.00. Apply H. B. MacNeal, 4727–31 Montrose Ave., Chicago, Ill. Describes the beginnings and development of the independent exchanges and the Association in an informal manner.

Great Britain, Dept. of Scientific and Industrial Research. Building Research Bulletin No. 6. The PREVENTION of CORROSION of LEAD in BUILDINGS, by F. L. Brady. 2 ed. Lond., His Majesty's Stationery Office, 1935. 4 p., illus., 10x6 in., paper, 3d. (Obtainable from British Library of Information, $.10.) A summary of a more detailed publication on the corrosion of lead by lime, cement, and soil.

SYMPOSIUM on the WELDING of IRON and STEEL. 2 vols. Lond., Iron and Steel Institute, 1935. v. 1, 676 p.; v. 2, 974 p., illus., 9x6 in., cloth, £2 2s. Contains 150 papers upon practice and problems in the engineering industries; welding practice, technique and apparatus; the metallurgy of welding; and specification, inspection, and testing.

CALCULUS. By H. H. Delaker and H. E. Hartig. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 276 p., illus., 9x6 in., cloth, $2.25. Intended for a first course in the subject and to develop the principles and methods hand in hand with their application to stated problems.

EINFÜHRUNG in die ANGEWANDTE AKUSTIK. By H. J. von Braunmühl and W. Weber. Leipzig, S. Hirzel, 1936. 216 p., illus., 9x6 in., paper, 9.20 rm.; bound, 10.70 rm. Presents basic principles briefly and discusses the instruments and processes used in receiving, transmitting, reproducing, recording, and measuring sound, and the acoustics of buildings.

GALVANIZING. By H. Bablik, translated by M. Juers-Budicky. 2 ed. Lond., E. & F. N. Spon; N. Y., Engineers Book Shop, 1936. 367 p., illus., 9x6 in., lea., $8.00. Hot galvanizing, electrogalvanizing, sherardizing, and spraying are all considered in this volume, which discusses the theory and practice of zinc coating.

Industrial Notes

TVA Contract to Delta-Star.—The Tennessee Valley Authority has awarded the Delta-Star Electric Co., Chicago, contracts amounting to $69,600.00, covering 2300-volt metal-clad switchgear and 161-kv switches for the Wheeler Dam development on the Tennessee River.

USL Welder Division Moves.—All USL arc welding equipment will hereafter be manufactured and sold by the Owen-Dyneto Corp., Syracuse, N. Y., the entire engineering staff and machinery of the welding division having been moved from the Niagara Falls plant of the USL Battery Corp. Both are subsidiaries of Electric Auto-Lite. The Owen-Dyneto Corp. manufactures motors, generators, battery charge regulators, etc., and along with the present product, a complete new line of arc welders is in the process of design and will incorporate many new and exclusive features, resulting in a more stable arc, greater welding speed as well as wider utility and more efficient performance. J. L. Fosnight will continue as sales manager of the electric arc welding division.

New Rural Line Publication.—The first issue of a new publication, "Rural Line Construction News," to be issued regularly, is now being distributed by the Copperweld Steel Co., Glassport, Pa. It describes power lines built with Copperweld-copper and Copperweld conductors. Details of construction and news items of interest to designers and builders of rural lines are also included.

New Dielectric Tester.—The Acme Electric & Mfg. Co., Cleveland, O., announces a new, hand portable dielectric or breakdown tester that not only indicates short or open circuits or grounds but actually checks circuits at approved standard testing voltages. According to the manufacturer the unit is fundamentally different in principle from other insulation testers in that it will permit actual application of the standard testing voltage of double the rated voltage plus 1000 to the equipment under test and thus prove the dielectric strength of the insulation to meet standard safety limits. The tester is a compact complete unit, equipped with a primary cord for plugging into a 110-volt, 60-cycle convenience outlet.

Hydrogen Cooling for Turbine-Generator.—A turbine-generator now under construction at the General Electric plant at Schenectady is unique in several respects. A 40,000-kw unit for the Appalachian Electric Power System, at Logan, W. Va., it will use steam at 1250 pounds pressure and 925 degrees Fahrenheit, higher than any heretofore employed in this country with a large turbine, and will be the first turbine-generator to employ hydrogen cooling. It will operate at 3,600 rpm. Hydrogen will reduce windage losses to 10 per cent of what they would be with air, and this results in an improvement in the efficiency of the generator of from 0.6 to 1.1 per cent, depending upon the size of the unit. Hydrogen requires considerably less pressure to circulate the necessary volume and it has many times the thermal conductivity of air. Although hydrogen results in a slight increase in capacity for a given physical size, the electrical characteristics still determine the capacity of the unit. Because of the more expensive construction required with hydrogen cooling, its use cannot be justified in small sizes. The suitability of hydrogen for use in electrical machinery is attested by 14 hydrogen-cooled synchronous condensers built or being built by General Electric, aggregating over 375,000 kv-a.

Trade Literature

Horn Gap Switches.—Bulletin 208-A, 4 pp. Describes the new S&C type RT, light duty, group-operated horn gap switch, especially designed for rural service. Schweitzer & Conrad, Inc., 4435 Ravenswood Ave., Chicago, Ill.

Rural Cable.—Bulletin GEA-2216, 24 pp. Describes various types of conductors, accessories, fittings, etc., recommended for rural electrification. Transformers, circuit breakers, fuse cutouts and lightning arresters for this purpose are also listed and described. General Electric Co., Schenectady, N. Y.

Speed Recorders.—Bulletin, 4 pp. Describes "Micromax" speed recorders for continuously indicating and recording speed, at any desired location, of turbines or other moving mechanism. The instrument can, if desired, actuate signals or any type of warning device. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Controlled Rectifiers.—Bulletin 8602. Describes controlled rectifiers to provide d-c power from an a-c power supply for small public and private telephone systems. These rectifiers are designed for 60-cycle, 3-phase, 208–220–240 nominal line volts input and for 50 $\pm$ $1^1/_2$ volt, 5 and 10-ampere outputs. Ward Leonard Electric Co., Mt. Vernon, N. Y.

Penn. R.R. Electrification.—Bulletin B-2058, 28 pp. Describes the electrification of the Pennsylvania Railroad system, illustrating every major unit, substation equipment, dispatching apparatus, and including a map of the power supply system from New York to Washington. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Ground Testing Instruments.—Catalog 1425, 16 pp. Describes "Megger" instruments for measuring resistance to earth of ground connections, such as driven rods, pipes, etc., and metallic structures of all kinds, including electric generating stations, substations, and transmission towers. James G. Biddle Co., 1211 Arch St., Philadelphia.

Copperweld Conductors.—Bulletin E. D. 1626. Contains complete wire tables and loading tables for Copperweld-Copper conductors, ranging in size from 4/0 to #8 A.W.G. copper equivalents, and combining the strength and mechanical stability of steel with the conductivity, durability and easy handling of copper. Copperweld Steel Co., Glassport, Pa.

Power Transformers.—Bulletin B-2043, 32 pp. Describes performance characteristics of power transformers, also insulation co-ordination, core and coil construction, cooling, painting, condenser bushing features, auxiliary devices and testing facilities. Fully illustrated and contains many views of outstanding installations. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Suspension Insulators.—Catalog, 76 pp. Describes "spring-ring" high voltage suspension insulators. In this type of insulator a spiral spring ring of steel wire is forced into the hollow head and expands into the wider cavity which is then filled with a lead alloy. Installations are illustrated. Hardware for making up complete suspension and tension strings is also described. Steatite & Porcelain Products, Ltd., Stourport, Worcestershire, England.

Ball Bearings.—Engineering Manual 35, 150 pp. Describes Fafnir ball bearings and heavy duty roller bearings. Summarizes the principles affecting the selection, application and operation of anti-friction bearings, with a complete tabulation of characteristics, dimensions and capacities. Because of the comprehensive nature and size of this volume, copies will be sent only to engineers actually engaged in the selection or maintenance of bearings. The Fafnir Bearing Co., New Britain, Conn.

Appliance Meter.—Bulletin, 4 pp. Describes a new appliance meter, essentially a watthour meter especially designed for measuring the amount of current consumed by an appliance during any desired period of time. The instrument can easily be connected into the circuit so that tests or checks can readily be made on the premises of a customer and consumption data secured under actual service conditions. These meters are available in 2-and 3-wire types and are supplied with either standard (slow moving) or special (fast) registers. Duncan Electric Co., Lafayette, Ind.

Water Wheel Generators.—Bulletin B-2062, 24 pp. Describes some of the outstanding recent water wheel generator installations. Includes installation views of many stations together with construction diagrams of several generators, such as for Boulder Dam, Norris Dam and Conowingo. Typical construction diagrams embrace engine type horizontal, medium size umbrella type, medium size vertical, bracket bearing horizontal and pedestal bearing horizontal generators. A list of large installations with their ratings is included. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.